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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

THE USE OF MUD-LADEN FLUID IN OIL AND GAS WELLS

BY
JAMES O. LEWIS
AND
WILLIAM F. McMURRAY

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THE USE OF MUD-LADEN FLUID IN OIL AND GAS WELLS.

INTRODUCTION.

The Bureau of Mines is investigating the technology of petroleum and its products, the investigation including well-drilling methods and the transportation, treatment, and utilization of petroleum and of natural gas, with especial reference to the prevention of waste and to increased efficiency in the development of oil and gas resources in land belonging to or controlled by the Government.

During the winter of 1912–13 the enormous waste of the gas encountered while drilling for oil in the Cushing field, Oklahoma, called forth protests from various sources, and appeal was made to the President of the United States and to the Secretary of the Interior in behalf of the landowner and of the public in general.

The facts were wanted regarding the amount of waste and the technical conditions that were responsible for practices causing it.

An investigation was ordered and conducted under the direct supervision of the late J. A. Holmes, the first Director of the Bureau of Mines. R. S. Blatchley was sent to investigate the amount of waste going on in the Mid-Continent fields.[a] In the latter part of March, 1913, J. A. Pollard and A. G. Heggem were sent to Oklahoma to study well-drilling methods with reference to the waste of gas from wells on Indian lands and to suggest means of preventing the waste of natural gas on such lands.

Pollard and Heggem decided that the mud-laden fluid process, which had been used successfully for some years in Texas, Louisiana, and California was the method that would meet the situation most efficiently and economically. The method was accordingly demonstrated in Oklahoma.

In 1914 Congress provided for the employment of six oil and gas inspectors to supervise oil and gas mining operations on lands of the Five Civilized Tribes in Oklahoma and to conduct investigations with a view to the prevention of waste. Positions under this appropriation have been held by William F. McMurray, James O. Lewis,

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[a] Blatchley, R. S., Waste of oil and gas in the Mid-Continent fields: Tech. Paper 45, Bureau of Mines, 1913, 54 pp.

Harry D. Aggers, Ralph R. Weed, George W. McPherson, James C. Fowler, Louis W. Courtney, and Carl H. Beal, the technical work of these men being directed by W. A. Williams, chief of the petroleum division, Bureau of Mines. After careful and impartial investigation of conditions in Oklahoma, these men also decided that the mud-laden fluid process was the one best adapted to prevent further wastes.

In 1915 laws were passed by the State of Oklahoma that provide for the conservation of natural gas and oil, authority being given to the corporation commission to make rules and regulations and to employ agents to enforce them. After hearings and investigations, the corporation commission reached substantially the same conclusions as the Federal agents regarding the importance of the wastes and the best methods of conserving the gas.

Technical Papers 66[a] and 68[b] were published by the Bureau of Mines in December, 1913, and January, 1914, respectively. Technical Paper 66 deals with the mud-laden fluid process in general and No. 68 with its application in Oklahoma. The interest aroused by these publications has been so widespread that within two years the first editions have been practically exhausted. Rather than reprint these publications, it has been considered advisable to replace them with the present report, which includes the results of more recent investigations.

The methods of using the mud-laden fluid are an outgrowth of the rotary drilling system, which was developed in Texas and later employed in Louisiana and California. Some of the principles of the use of mud fluid had been observed and used to a limited extent for a long time in cable-tool drilling. So far as known it was first used successfully with a circulator and cable tools in the Coalinga field, California, in 1906, Harry D. Aggers, one of the contributors to this paper, working on the well. The part of the Bureau of Mines has been to call attention to its merits and to demonstrate its practical use in fields like those of the Mid-Continent.

ACKNOWLEDGMENT.

This report was written in collaboration with J. A. Pollard, A. G. Heggem, H. D. Aggers, W. A. Williams, L. W. Courtney, G. W. McPherson, C. H. Beal, and J. C. Fowler, whose connection with the investigation covered by this report has been mentioned above. Material from Technical Papers 66,[c] 68,[c] and 130[d] of the Bureau of

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[a] Pollard, J. A., and Heggem, A. G., Mud-laden fluid applied to well drilling: Tech. Paper 66, Bureau of Mines, 1913, 21 pp.

[b] Heggem, A. G., and Pollard, J. A., Drilling wells in Oklahoma by the mud-laden fluid method: Tech. Paper 68, Bureau of Mines, 1914, 27 pp.

[c] See footnote references above.

[d] McMurray, W. F., and Lewis, J. O., Underground wastes in oil and gas fields and methods of prevention: Tech. Paper 130, Bureau of Mines, 1916, 31 pp.

Mines has been used freely. In addition to the information gathered by the Bureau of Mines and the oil and gas inspectors in the Five Civilized Tribes, information of value has been acquired from the gas conservation officers for the State of Oklahoma and from many individuals, associations, and companies.

WASTES OF NATURAL GAS.

The Bureau of Mines since its inception in 1910 has directed much effort toward informing the public of the importance of the wastes of natural gas and toward finding preventive measures. In order to convey an idea of the necessity of more efficient methods of utilization, a few cases of the waste of gas are cited.

In the Findlay field, Ohio, the Karg well alone wasted not less than 1,500,000,000 cubic feet.[a]

The Minshall gas well, drilled in the Macksburg field of Ohio, was allowed to blow into the air for a period of 10 years. It was put under partial control in 1885, when it had a measured volume of 4,500,000 cubic feet daily and a rock pressure of 425 pounds. It was not entirely closed in until two years later. The total volume wasted could not have been less than 15,000,000,000 cubic feet, with a fuel value equivalent to 750,000 tons of coal.[b]

White[c] speaks of waste in Kentucky and West Virginia as follows:

> From one well in eastern Kentucky there poured a stream of gas for a period of 20 years without any attempt to shut it in or utilize it, the amount of which it has been figured was worth at current prices more than $3,000,000.
>
> In my own State of West Virginia only eight years ago not less than 500,000,000 cubic feet of this precious gas was daily escaping into the air from two counties alone, practically all of which was easily preventable by a moderate expenditure for additional casing.

The commission on the conservation of natural resources in Louisiana found that at one time 75,000,000 cubic feet of gas was wasting daily in the Shreveport field, one well alone wasting $2,000 worth. Arnold and Clapp state that at certain times as much as 400,000,000 cubic feet has been wasted daily in the Caddo field, Louisiana, and that two wells with an estimated volume of 20,000,000 to 30,000,000 cubic feet daily burned for several years without restraint.[d]

In drilling for oil in the Buena Vista Hills field, California, one gas well was opened that wasted at least 55,000,000 cubic feet per day for three months before it was finally got under control. At least 5,000,000,000 cubic feet of gas, valued at 25 cents per 1,000 cubic feet, or $1,250,000, was lost from this one well alone.[e]

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[a] Orton, E., and others, Economic geology: Ohio Geol. Survey, vol. 6, p. 133, 1888.

[b] Statement of Orton Dun, Marietta, Ohio.

[c] White, I. C., Address at conference on the conservation of natural resources, May 13, 1908.

[d] Arnold, Ralph, and Clapp, F. G., Wastes in the production and utilization of natural gas and means for their prevention: Tech. Paper 38, Bureau of Mines, 1913, pp. 8–9.

[e] Arnold, Ralph, and Clapp, F. G., Op. cit., p. 10.

One well in the Petrolia field near Wichita Falls, Tex., flowed unrestricted for 11 months, during which time the loss is estimated to have been approximately 4,000,000,000 cubic feet.[a]

Blatchley estimated that the waste of gas in the Mid-Continent fields to the end of 1912 would be 425,000,000,000 cubic feet as a conservative estimate.[b] The heating value would be equivalent to approximately 21,250,000 tons of coal.

One well in the Osage Reservation, Okla., was allowed to blow for a year and a half, at the end of which time it was shut in by the use of mud-laden fluid and was found to gage 12,500,000 cubic feet daily from one sand alone. The amount of gas which escaped to the surface could not have been less than 6,000,000,000 cubic feet. The total waste of gas from this and other sands, both to the surface and underground, was far greater.

A shallow gas well, 520 feet deep, located in the Cushing field, Oklahoma, wasted 1,500,000,000 cubic feet of gas in 50 days. Practically every deep well in this field wasted many millions of cubic feet of gas while drilling. Wells wasting 25,000,000 cubic feet or more daily were numerous. At times the waste exceeded 500,000,000 cubic feet daily. In still weather the field was overhung with a haze of gas and oil vapors, and the amount of gas in the air was so great that no fires, open lights, or automobiles were allowed among the wells. Much damage was done and many lives were lost by the ignition of gas which had traveled many hundreds of feet from its source. Probably the waste in the Cushing field has never been exceeded in any other field. In May, 1915, an estimate was made by W. F. McMurray and H. D. Aggers, United States oil and gas inspectors, which showed that 207,000,000 cubic feet of gas was wasting into the air from 360 wells only. This was after the greatest waste had taken place, and included less than half of the wells. There is no way of determining the total waste, but for the three years ending in 1915, it was probably not less than 250,000,000,000 cubic feet; equivalent in fuel value to 12,500,000 tons of coal. For a period of many months, the rock pressure declined at the rate of one or two pounds a day. By far the largest part of this waste could have been prevented without difficulty by the use of mud-laden fluid, and it is evident that the saving of gas would have recompensed the operators many times over for the comparatively small additional expense.

These cases represent only a few of the more striking instances of waste in various fields of the United States. There are, also, thousands of instances individually of less importance, whose aggregate waste greatly exceeds that from the smaller number of conspicuously large wells. Frequently the amount of gas utilized has been but a small percentage of the content of the field, and it is believed to be no exaggeration to say that not half of the natural gas so far developed has been utilized.

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[a] Blatchley, R. S., Waste of oil and gas in the Mid-Continent fields: Tech. Paper 45, Bureau of Mines, 1913, p. 43.

[b] Blatchley, R. S., Op. cit., p. 47.

WAYS IN WHICH NATURAL GAS IS WASTED.

Ways in which natural gas is wasted from wells for which mud-laden fluid may be employed as a preventive measure, are: (1) During the drilling of wells; (2) from behind casings; (3) from uncontrolled or wild wells; (4) from wells on fire; (5) through defective casing, packers, or casing seats; (6) by unsystematic ways of casing wells in a field; (7) by not separating gas sands from producing oil sands; (8) by migration from gas sands into other strata; (9) by the drowning out of gas by water from other strata; (10) from improperly plugged wells.

The larger part of the waste that has taken place in the past could have been prevented with the knowledge and equipment then available. However, some of the wastes could have been controlled only by the knowledge that has been gained in recent years. At present, cases where waste can not be prevented by reasonable foresight and expense are exceptional.

The greatest wastes of natural gas have taken place in fields which were being developed for oil. In most oil fields, much gas is found in sands above the oil or in the same sand as the oil. If a well is being drilled by one of the usual methods, the gas becomes a hindrance to drilling, and the driller regards it as a nuisance. Or the gas may be found in a field where it has little or no immediate commercial value, and hence is allowed to escape into the air without restraint. It has been a frequent practice to allow the gas to escape freely while the well is being drilled through the gas-bearing sands in search of oil (Pl. I, *A*), or the gas has been allowed to blow into the air for long periods, for the purpose of reducing the volume and pressure so that drilling may be conducted with less effort in later wells. Such great wastes are believed to be altogether unnecessary, for the preventive methods that are described in this paper have proved to be entirely practicable.

In a field where much gas overlies the oil, the usual dry-hole methods of drilling can not be employed without danger and waste. In the Mid-Continent fields alone during recent years there have been a large number of deaths and serious accidents from burning gas (see Pl. I, *B*) while wells were being drilled. These accidents and the great hazard from fire risk, to say nothing of the great waste of gas, could not have happened if the mud-fluid method were properly used.

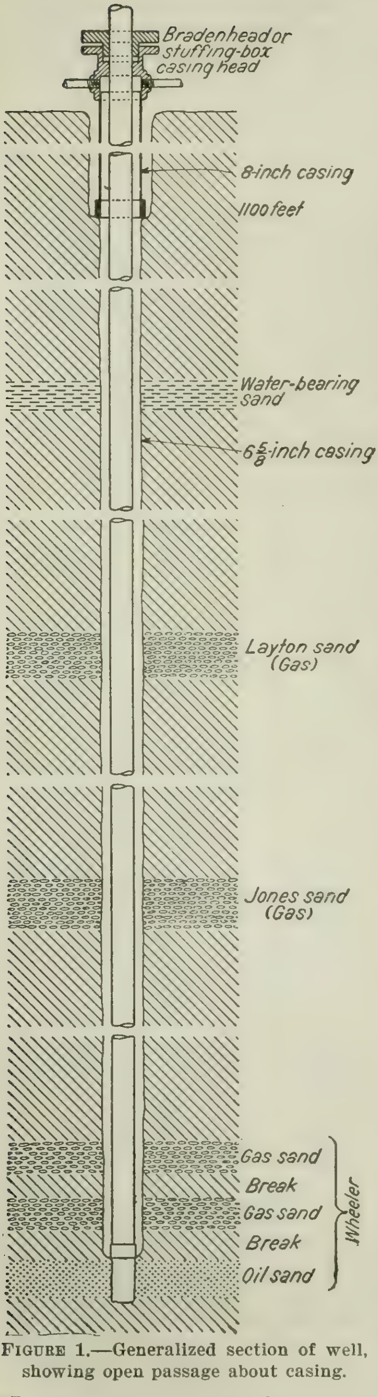

FIGURE 1.—Generalized section of well, showing open passage about casing.

To place a casing properly, the drill hole must be large enough to allow the couplings to slip freely down the hole. There is, therefore, a space of an inch or more between the casing and the walls of the hole (fig. 1). This makes a free path around the casing, which allows oil, gas, or water to pass freely from one stratum to another or to the surface. The water may drown out the oil or gas, the gas may escape into porous strata, thus reducing the volume and pressure until it is of no commercial value, or fresh water may be spoiled by oil or salt water. By the use of mud fluid this intercommunication behind the casing is prevented (fig. 2).

IMPORTANCE OF UNDERGROUND WASTE.

The importance of underground waste has not been given as much attention as the facts warrant.[a] To prevent such waste it is necessary to confine closely oil and gas to the strata in which they are found, otherwise they will dissipate through the formations and may not be recovered (fig. 3). One of the most common arguments against shutting in gas has been that once a deposit has been opened up, the gas can not be held underground, but in some way escapes, and therefore any expense incurred in shutting it in is not warranted. If the gas is closely confined to its original stratum it can be held for future markets. It is believed that the use of the mud-laden fluid process will conserve the gas at expenses which the future returns will more than justify.

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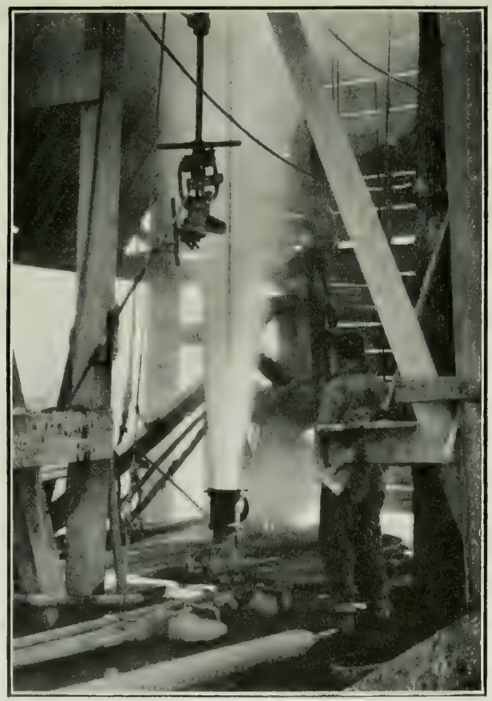
[a] McMurray, W. F., and Lewis, J. O., Underground wastes in oil and gas fields and methods of prevention: Tech. Paper 130, Bureau of Mines, 1916, 31 pp.



A. GAS WASTING FROM A WELL BEING DRILLED

B. A BURNING GAS WELL.

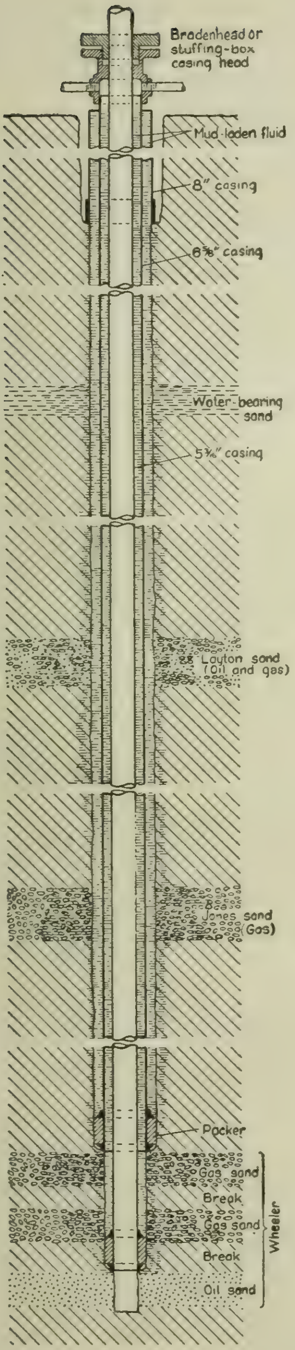


FIGURE 2.—Generalized section of "combination" well finished with mud-laden fluid.

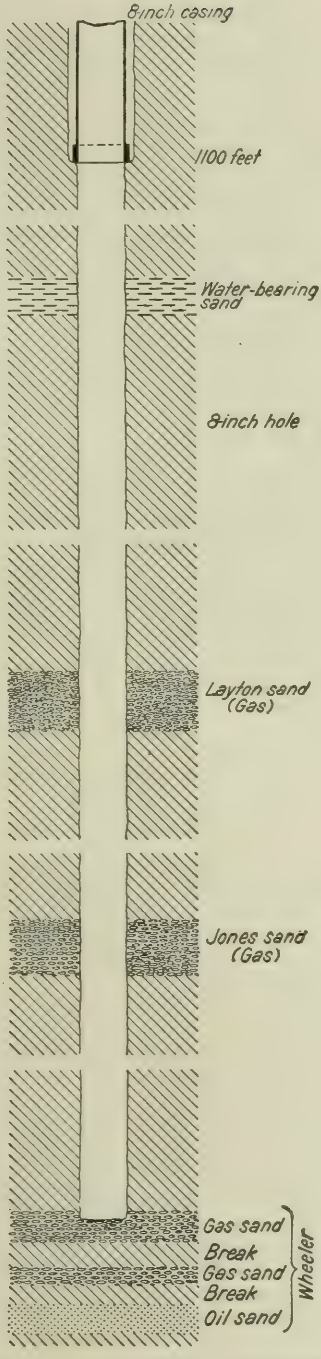


FIGURE 3.—Generalized section of uncased hole, permitting communication between formations.

To show that underground waste is a fact which has been established for many years, the following is quoted from the first report of the supervisor of natural gas in Indiana, issued in 1891:[a]

> I would also recommend the passage of a law regulating the packing of wells. A large number of wells have what is known as wall packers. By this is meant that the packer and tubing is anchored to the wall of the well in the shales, in many instances as much as four and five hundred feet from the bottom of the well. Incalculable injury is, in nearly every case, done by this method. The gas, after its release from the Trenton rock, permeates every portion of porous rock that forms the wall of the well below the point at which the well is packed. It spreads itself laterally through every crevice and opening that is found, and thus an enormous waste is maintained.
>
> In many parts of the field we find gas escaping through the earth and bubbling up through the water in the streams and in water wells. In some instances the escape into water wells has been so strong that the wells have been closed in and the gas piped into the houses adjoining and found sufficient for domestic consumption.
>
> All this may be attributed to the insufficient packing of the wells in the vicinity. The great upheaval of earth and rocks, and the explosion which followed in the vicinity of Waldron, Shelby County, which occurred August 11, 1890, was due to the gas escaping through the shales and below the packers from the wells at Waldron and St. Paul. The gas escaping laterally through the shales collected in subterranean reservoirs until the pressure became so great as to cause the upheaval.
>
> The waste from this cause has resulted in vast injury to the field in different localities by reducing the pressure, and the consequent introduction of salt water.

WAYS AND ADVANTAGES OF USING MUD-LADEN FLUID.

DESCRIPTION OF MUD-LADEN FLUID.

In this bulletin the term "mud-laden fluid" is applied to a mixture of water with any clayey material which will remain suspended in water for a considerable time and is free from sand, lime cuttings, or similar materials.

Some oil workers have thought "mud-laden fluid" implies the use of any of the drillings from the well, but this is not the case, for if the coarse materials in the drillings, such as sand, limestone fragments, etc., are left in the fluid they will settle and are likely to pack around the tools or the casing and cause serious troubles, specific instances of which are described in Bureau of Mines Technical Paper 68.[b] The fine, sticky clays that are in many localities termed "gumbo" are well suited for the purpose, but clay or shale from other formations may be used, provided it is separated from the sand and other coarse materials and only the part that will remain suspended in water is used. It is possible to use drillings from almost any formation containing clay or shale after proper treatment by settling.

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[a] Gorby, S. S., and others, Indiana, Geology and natural history: 17th Ann. Rept. State Geologist, 1891, p. 338.

[b] Heggem, A. G., and Pollard, J. A., Drilling wells in Oklahoma by the mud-laden fluid method: Tech. Paper 68, Bureau of Mines, 1914, 27 pp.

CONSISTENCY OF FLUID TO BE USED.

The consistency of the fluid should be varied according to the conditions for which it is to be employed. Most frequently mixtures with a specific gravity of 1.05 to 1.15 are used in drilling—that is, 5 to 15 per cent heavier than water. When the fluid is not used to drill in, thicker fluid is often employed, which has the advantages of greater weight and of clogging up the pores more readily. Experience soon enables the operator to judge the consistency of fluid required for practical uses.

The operator who is unfamiliar with the use of mud-laden fluid is likely to use it too thin. This has been the cause of much trouble in Oklahoma. Such fluid acts like clear water. It will not clog the pores of the sand readily and hence will be forced into them for considerable distances, and in some instances near-by wells have been affected. It is also likely to cause caving and is injurious to the sand, or it may not have sufficient weight to overcome high-pressure gas. The only limit to the thickness of the fluid which it is possible to employ is whether or not it can be handled by the pumps, but it must be a fluid and not a pasty clay.

An idea of the consistency ordinarily required can be obtained by comparing the action of a stream of clear water with that of a stream of sand pumpings or muddy water running in a ditch. The sand pumpings contain clayey material which is deposited on the walls and especially the bottom of the ditch, where it forms an ever-thickening protective coating, whereas clear water cuts away the sides and bottom of the ditch and may cause it to cave. Between clear water and water containing more mud than it can hold in suspension, it is possible to find a mixture of clay and water that will deposit particles of clay as a fine protective coating, while the rest of the clay remains in suspension and passes through the ditch.

VARIATION IN FLUID PREPARED FROM DIFFERENT CLAYS OR SHALES.

There is considerable variation in the nature of fluids derived from different clays or shales. When the same volumes of two different materials are mixed with the same volumes of water the resulting fluids may differ considerably in specific gravity, or of two fluids of the same specific gravity one may be more viscous or thicker than the other.

SETTLING OF MUD FLUID.

An important consideration and one that has raised numerous inquiries is the amount of settling which a mud fluid will undergo. It is a well-known property of clays and similar colloidal materials that they will remain in suspension indefinitely. One sample of mud fluid has been standing for three years without appreciable settling and has not solidified. Numerous experiments conducted on short columns of fluid have shown that it will settle rapidly for a few hours, after which the rate of settling is very slow, and after a few days is practically nil. There is a surprising difference in what the maximum density may be. Of six samples collected from oil wells in southern California and allowed to settle two months, the variation was 10 to 30 per cent excess in weight over that of clear water. In each case the settled part was still fluid and not very viscous. It was also found that the final density in a short column of fluid is governed largely by the original density. For instance, two fluids were prepared by mixing the same kind of material in different proportions with water, one having a density 5 per cent greater than water and the other a density 15 per cent greater than water. The first settled to a much lighter consistency than the second.

When the fluid settles in a short tube it separates into clear or turbid water at the top and mud fluid at the bottom. The specific gravity of the fluid at the bottom varies in the manner outlined above. The proportion of water to that of the fluid which settled out depends principally on the specific gravity of the original mud fluid, and the lighter the original fluid the greater is the proportion of water to the settled fluid in the bottom of the tube. Although the settling takes place quickly in a short tube, the same rate of settling applied to a long column of fluid in a well means that it takes a very long time for it to settle, and in fact there is reason to suspect that behind the casing complete settling does not take place even after long periods of time.

When the fluid has settled for some time in a well there may be water near the top. As the weight of material in the well remains the same, the pressure at the bottom of the column of fluid is the same as before the settling occurred, but near the top the pressure will be decreased. However, the mud has sealed the formations, and no oil or gas can pass through unless the pressure within the strata is sufficient to force the mud out of the pores and to overcome the water pressure in the hole. When the fluid is to be left in the well it is advisable to use a heavy fluid that will settle very little. If there should be formations near the top of the hole which it is important to protect, fresh mud fluid can be put in after the original fluid has had a chance to settle.

All the evidence obtainable from practical experience points to the fact that mud fluid, properly mixed and employed, does not solidify behind the casing, even in deep wells and after long periods. This has been the experience in Texas and Louisiana with rotary wells, and in Ohio with wells drilled by cable tools.

DETRIMENTAL EFFECT OF COARSE MATERIALS IN THE FLUID.

Sand or other coarse materials in the fluid will ordinarily settle out, but if the fluid is too thick they may be held in suspension, and in such cases it has been found by experiment that the sand suspended in the fluid offers much resistance to anything being forced through. The action on a string of casing of sand suspended in the fluid is undoubtedly to increase the friction on the casing, and may be instrumental in making it so " loggy " that it can not be moved.

ACTION OF MUD FLUID ON POROUS FORMATIONS.

The action of mud-laden fluid in a sand or other porous formation can be likened to the action of muddy water going through a filter. In any filter that has been used for some time it will be found that most of the sediment from the water has been deposited on the surface of the filter, but some of it has entered the filter, the proportion diminishing with the distance penetrated. The distance to which mud from the fluid in the well will penetrate a porous formation depends partly on the combined pressure produced by the column of fluid and the pump, and partly on the consistency of the fluid and the porosity of the formation. At first the fluid will enter the formation, but finally the mud will clog the pores and no more water will go through. Ordinarily, if a thick fluid is used on the sands encountered in the well, it will not penetrate to any great distance even under high pressure, but if the fluid is too thin it may not clog the pores readily and will act more like clear water, which may enter a sand indefinitely. Occasionally a very coarse sand, a fissured formation, or a porous limestone is found into which even thick fluid may penetrate for some distance.

When no more fluid will enter the sand or porous formation a barrier or plug that is impervious to oil, gas, or water has been formed within the sand surrounding the hole. This plug is held in place partly by the resistance to movement of the mud deposited in the pores of the formation, but principally by the excess of pressure produced by the column of fluid in the hole. If the column of fluid is removed the pressure within the sand will usually force out the mud, and the oil, gas, or water will enter the hole again; but as long as a sufficient column of fluid remains in the hole the contents of the sealed formation can not enter the hole. It is believed that the efficiency in sealing off the porous formations in a well depends more upon the mud forced into the pores of the formation and retained by the weight of the column of fluid than upon the mud plastered on the walls of the hole, although the mud coating probably aids in protecting the walls from caving.

When a well has been treated with mud fluid the contents of each formation is confined to its original stratum, so that there can be no movement of oil, water, or gas either from the sands into the well, from the well into the sands, or from one sand into another. Thus waste and intermingling are prevented, corrosive waters can not reach and attack the casing, and the strata are entirely sealed off from each other as they were before the well was drilled.

Mud fluid, besides preventing caving, as stated above, is also an aid in keeping loose sands from entering the hole. The fluid clogs up all pores or crevices, and makes a solid wall which the weight of the fluid in the hole will hold up. Furthermore, the mud which has entered the formations, or is plastered on the walls, protects them from contact with air and water, which would cause slaking and caving. The fluid is especially helpful in drilling through a loose sand that otherwise would run into the hole and make drilling difficult.

DISADVANTAGES OF USING CLEAR WATER.

Some drillers contend that clear water should have the same effect as the mud-laden fluid, but experience has shown that it does not. Many wells can not be filled with clear water, because the water continues to flow into the sand indefinitely with no clogging effect and consequently does not rise high enough in the well to give sufficient pressure to overcome that of the gas. Moreover, the action of the water on the walls of the hole causes caving, and an attempt to use clear water in a well invites trouble and may injure the producing sands.

The action of the mud fluid is entirely dissimilar to that of clear water. The fluid enters the porous stratum for a short distance and deposits mud, which clogs the openings and finally prevents further inflow of fluid. Clear water thus lacks some of the essential properties of mud fluid, such as the clogging effect and the greater weight.

PREPARING MUD-LADEN FLUID.

The mud-laden fluid may be prepared from clay obtained from surface deposits or from material derived from drillings. Ordinarily there will be enough clayey or shaley material in the formations encountered in the well to provide all the fluid necessary. This has been found true both in drilling with rotary tools and with cable tools. In order to save time in preparing the fluid for use in the well, it is recommended that a slush pit, having a capacity of about 300 barrels, be constructed close to the drill rig, into which materials suitable for making mud-laden fluid may be run whenever encountered in drilling. Drillings from sandstones and limestones should not be allowed to enter the pit. The slush pit can be provided with slight expense, and the mud fluid can be mixed and prepared in a few hours by ordinary unskilled labor whenever it is desired. Figure 4 shows one arrangement for a slush pit and settling pits. An arrangement for use with the circulator, a device for circulating mud fluid in a well, is shown in figure 5.

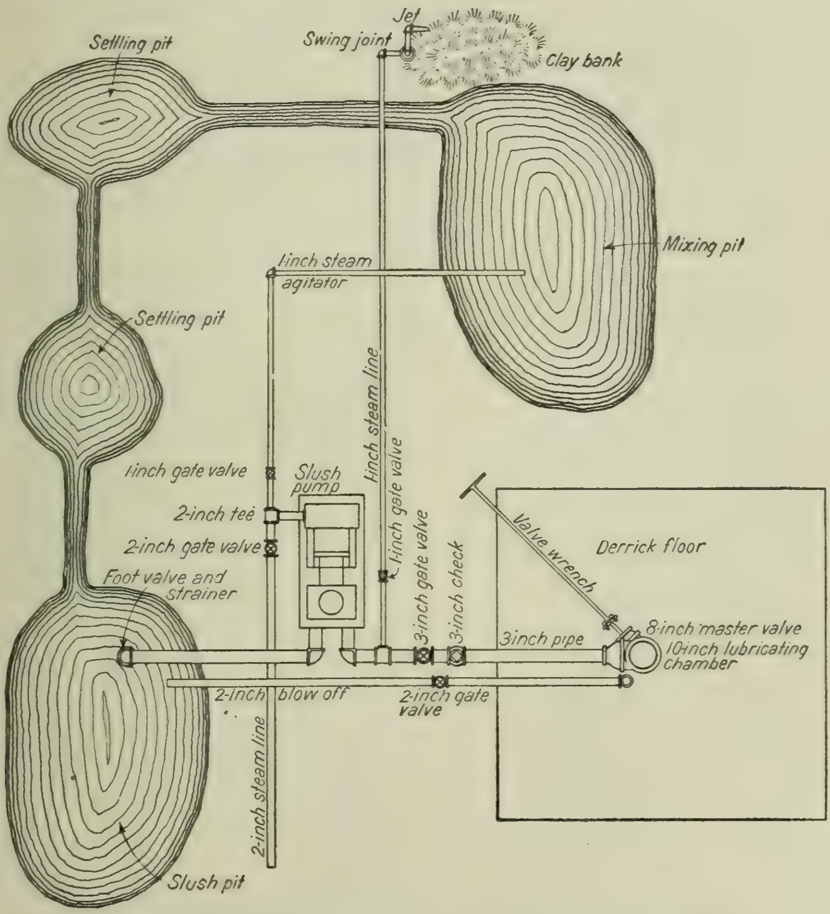

FIGURE 4.—Ground plan of equipment used in handling mud-laden fluid.

Settling out sand, limestone cuttings, etc., in order to avoid freezing of casing and of tools, is important.

METHODS OF INTRODUCING MUD-LADEN FLUID INTO THE WELL.

The method of introducing mud fluid into a well is varied according to the circumstances under which it is to be employed.

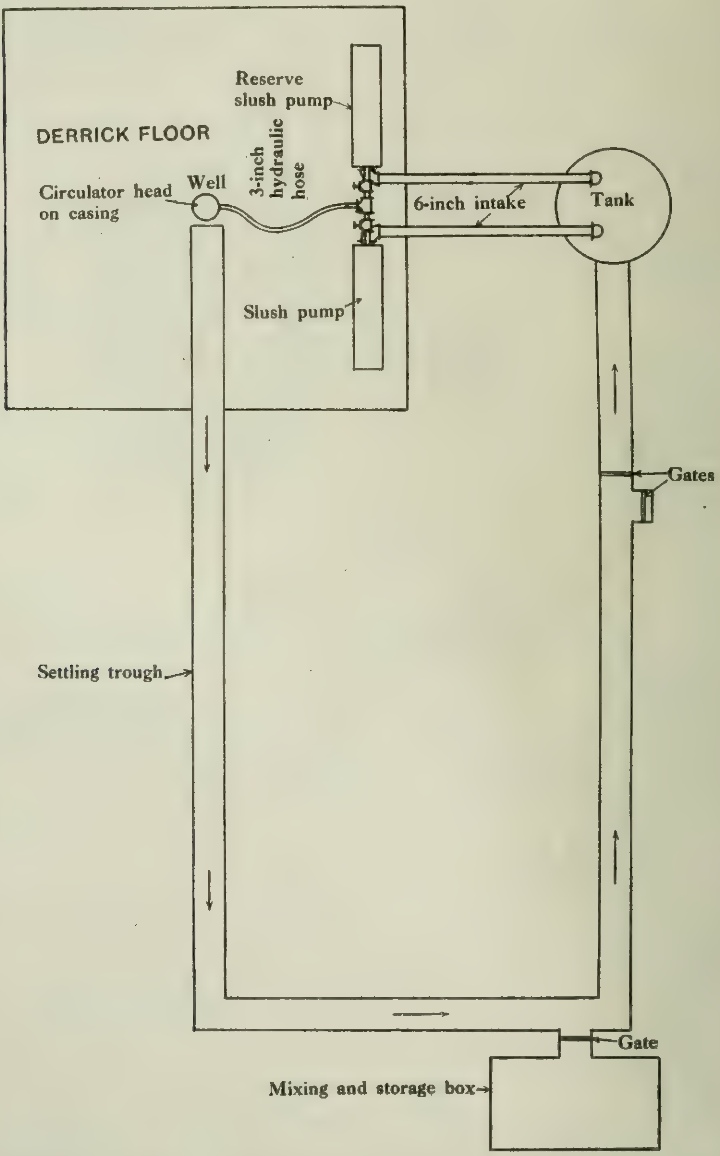

FIGURE 5.—Diagram of equipment for circulating mud-laden fluid in a well.

It is not advisable to let the fluid run down the walls of a dry hole because to do so may cause them to cave. If there is a considerable amount of open hole in a well, it should be filled by dumping the fluid into the bottom of the hole with a bailer, or introducing it through a string of tubing or casing which reaches to the bottom. When high-pressure gas has been struck special methods must be employed.

THE LUBRICATOR METHOD.

If gas has been struck and the well is blowing gas, and the conditions are such that the gas can be shut in, recourse may be had to a method which has been named the lubricator system, one arrangement of which is shown in figure 6. The general features of this particular arrangement were devised by A. G. Heggem, who employed his control casing head instead of a master valve and tee. The apparatus consists of two joints of casing, preferably 10-inch casing, with a tee at the bottom, which in turn is connected by a nipple to a master valve placed on the head of the well. A 2-inch or 3-inch pipe leads from the slush pump into the tee at the bottom of the lubricator, with a check valve near the tee and an emergency gate valve near the pump. A 2-inch pipe leads from the top of the lubricator down the side, to which it is lashed, and thence to the slush pit, a gate valve being placed outside the derrick at some convenient point. The apparatus can be assembled and then placed on the well as a unit. In this manner the danger of handling single fit-

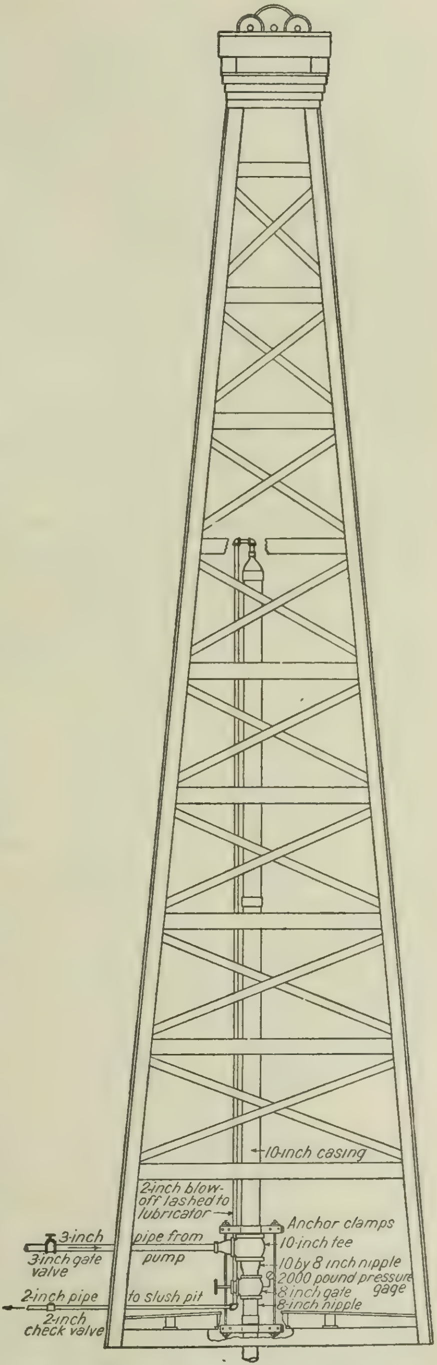

FIGURE 6.—Device for introducing mud-laden fluid into a well under gas pressure.

tings or putting a valve on a gas well is avoided. If a long crowfoot wrench is attached to the master valve so that it can be operated from without the derrick, there is ordinarily no necessity for any worker to be in the derrick while the apparatus is being used, thus reducing to a minimum the danger of shutting in a high-pressure gas well. After the lubricator has been set up the ordinary crew can operate it.

When the lubricator has been set up the master valve is closed and the valves on the pipe from the pump to the lubricator and on the blow-off pipe are opened. The mud-laden fluid is pumped into the lubricator until it is filled and fluid shows in the blow-off; then the blow-off valve is closed and the master valve is opened. The fluid then drops to the bottom of the well, being replaced in the lubricator by an equal volume of gas. After waiting two or three minutes for the lubricator to empty, the master valve is then closed and the blow-off valve is opened. The gas in the lubricator escapes through the blow-off valve, carrying into the slush pit the small amount of mud fluid that may have remained in the apparatus. The lubricator is then filled again, the blow-off valve is closed, and the master valve opened. These operations are repeated until the column of fluid in the well overcomes the gas pressure to such an extent that the pump can force the mud fluid in against the gas pressure and fill the well.

It has been found desirable in some cases to move the casing while lubrication is going on, in order to keep the pipe free. This can be done by handling the whole apparatus in slings, reaching from the collar below the master gate to the casing block above the lubricator. If the gas pressure in the well has not already been overcome by that of the fluid in the hole, the casing being filled must be worked up and down through a bradenhead or casing head of the stuffing-box type attached to the next larger string of casing; otherwise the fluid would be blown out between the casings when the inner casing was lifted off the seat.

PUTTING THE FLUID IN A WELL THAT CAN NOT BE SHUT IN.

When gas is blowing from a well and can not be shut in, perhaps because of the small amount of surface casing in the well, or possibly because the casing was not properly seated so that the gas is forced up outside of the casing when the valve is closed, the method shown in figure 7 is used. At such a well it becomes necessary to insert a string of tubing with a back-pressure valve placed on the bottom, or preferably a wooden plug, which is advisable because a back-pressure valve may get out of order at some critical moment. The wooden plug is driven lightly into the bottom of the tubing, so that it can be forced out when desired, but is tight enough so that no gas can enter the tubing. After the tubing has been lowered to the proper depth it is packed or sealed with a casing tee previously placed on the well. To control the flow of gas, a gate valve should be placed on a lateral discharge of this tee. As soon as the mud fluid has started down the well through the tubing the gate valve on the tee can be partly closed in such a manner as to throttle the outlet and to prevent the mud-laden fluid from being forced out of the well by the gas pressure. The weight of the fluid when it reaches the bottom of the tubing will force out the wooden plug.

The amount of throttling necessary can be determined only by the man in charge, as similar conditions will not prevail at any two wells. However, it is not difficult to ascertain how much the gas should be throttled. If the well is emitting water with the gas, the fluid can be put in just as readily by this method, and a well with a capacity of as much as 40,000,000 cubic feet of gas and several thousand barrels of water daily has been quickly controlled. As is evident, the full rock pressure of a well is not maintained in the casing, and consequently no blow-out will follow, as would happen if the gas were forced to the surface on the outside of the casing.

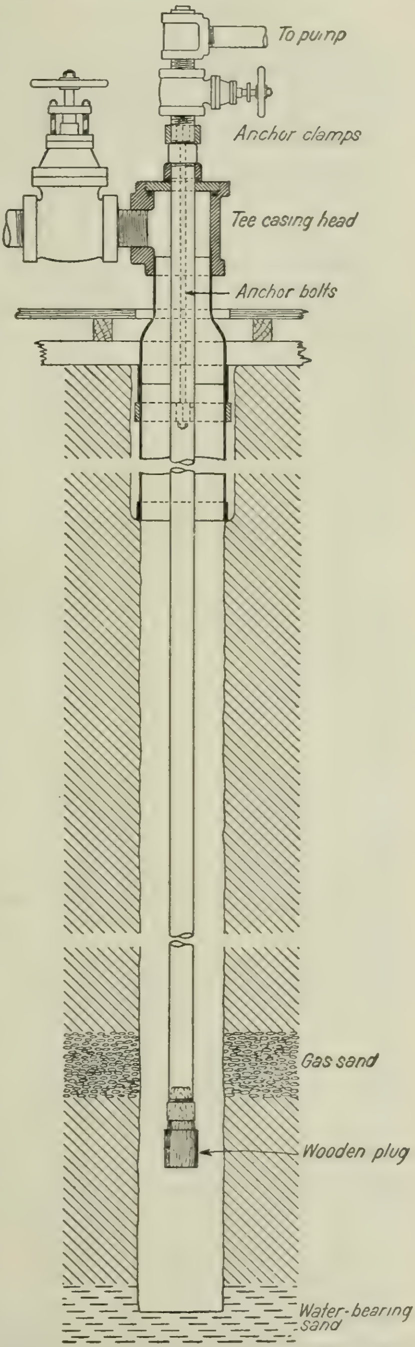

FIGURE 7.—Equipment for introducing mud-laden fluid into a well that can not be shut in. Well section is generalized.

OTHER METHODS OF INTRODUCING THE FLUID.

The throttling method can also be used to advantage instead of the lubricator, in wells that can be shut in, if the volume and pressure of the gas is not too great. The fluid is pumped in directly without use of the equalizing chamber. As care must be taken to prevent the internal pressure from splitting the pipe through which the fluid is to be introduced, it is not advisable to use light casing when it is to be subjected to very high pressure.

It sometimes becomes necessary to introduce the mud fluid between casings from the top of the well. This should be avoided if possible, for the reason that the fluid will carry down cavings and other material which may lodge against the couplings at some point in the hole and form a bridge which will keep the fluid from reaching the bottom, or will pack around the casing in such a way that it may not be possible to pull the casing should it ever be desired to do so. Experience shows that it is more difficult to pull casing that has been "mudded" in this way.

If the gas pressure in the well is not too high, a string of casing can be "mudded" by the following method, which, however, is not recommended, for the reasons given below. The casing is set below the gas sand and is then filled to the top with mud fluid. When the casing is raised, the fluid will rise outside the casing until a level is reached with that inside of the casing. The well is usually filled to a point between two-thirds and three-fourths of its depth, and the height of the fluid ordinarily is sufficient to overcome the gas pressure. The hole is then filled to the top, the casing is seated, and the fluid bailed out from the inside.

Although this is a very simple and quick method, it has serious disadvantages. If the well is drilled through gas, the gas is wasted while the sand is being drilled through and until the fluid is placed behind the casing. There is also great danger that the casing may freeze or collapse and can not be reseated so that it will hold in the fluid. In a well 1,000 feet deep, the pressure of the fluid at the bottom will be 500 to 600 pounds per square inch, and will increase in deeper wells proportionately. When the pipe is raised, the shoulder on which the casing rests and the walls of the hole have to bear the sudden rush of this large weight of fluid, and unless they are of very firm rock, the shoulder will be destroyed and the walls of the hole gouged out, which will make it very difficult to reseat the casing securely. Furthermore, the material loosened from the walls of the hole will be carried up between the casing and the walls of the hole for some distance, and then will settle back against the collars, and is likely to freeze the pipe, or it will be jammed suddenly under the collars one or two joints from the bottom with such great pressure as to crush the casing. In two instances this method resulted in crushing the casing at the second joint from the bottom. In many others it was followed by trouble in seating or moving the casing.

PROCEDURE WHEN THE PRESSURE OF THE COLUMN OF FLUID IS INSUFFICIENT.

It occasionally happens that the pressure in a gas, oil, or water-bearing sand may exceed the pressure exerted by a column of fluid extending to the top of the well. When this happens, the fluid is blown out and the well goes "wild." It then becomes necessary to use a pump to overcome the gas pressure and to force the mud-laden fluid into the sand. Sufficient pressure should be allowed to remain on the well for at least two or three hours and then the pressure should be relieved slowly and carefully. If the pressure is suddenly reduced, the column of fluid may be violently ejected and the casing, fittings, and derrick wrecked. In some instances it has been found necessary to maintain the pressure for six hours or more.

SEALING OFF VERY POROUS OR COARSE-GRAINED FORMATIONS.

Generally when a sand is to be "mudded off," a comparatively thin mixture is first used, and this is followed up by a thick fluid. If the fluid is to be left in the well, it should be thickened so that there will be but little settling.

Occasionally a formation may be struck which is so porous and so coarse grained that difficulty will be experienced in clogging it with the fluid. If it can not be sealed off with the thickest fluid possible to use, it may be necessary to employ substances like sawdust, chopped straw or chopped rope, or other materials which will pack into the pores of the sand so that it will hold the mud. Trouble may arise from such material clogging the pump, but if necessary the lubricator can be employed in such a way that the material can be introduced without passing it through the pump.

TYPE OF PUMP TO BE USED WITH MUD FLUID.

A pump specially designed for handling thick mud fluid should be used. The type is generally known in the oil fields as a "slush pump" and is fitted with removable liners and insert valves. An 8-inch by 5-inch by 10-inch pump, weighing less than 2,000 pounds, has been successfully used on small wells in Oklahoma. Such a pump has the advantage of being inexpensive and easily moved. Where the gas pressure is high, a larger pump capable of greater pressure and of handling a larger volume of fluid is necessary. A 10-inch by 6-inch by 12-inch pump, weighing about 4,700 pounds, will meet anything but extraordinary conditions.

DRILLING WITH FLUID IN THE HOLE.

The presence of the mud-laden fluid in the well does not prevent drilling with cable tools, and the bailer can be used in the usual way for removing the drillings from the bottom of the hole. Drilling with cable tools in mud fluid has been a matter of ordinary practice in the California fields for many years both with and without the use of the circulator. Although it is not as fast as drilling in a dry hole, where conditions are favorable, there are places where the former method will have many advantages over the dry-hole method and sometimes may be faster and cheaper.

Drilling a well through a gas sand by the dry-hole method causes great waste. The free escape of gas has resulted in many disastrous fires and other damage to life and property. While the gas is escaping, no fires can be lighted near the well, so it is often necessary to stop work at night or in cold weather. Even work on wells near by may be stopped. Sometimes the gas pressure interferes with the tools dropping in the hole and makes drilling dangerous, slow, and occasionally impossible. Under such circumstances it may be necessary to discontinue drilling until the volume and pressure of the gas has been reduced. Either the well is allowed to blow without restraint or it is shut in and called a gas well, although there may be no market for the gas at the time. If, however, drilling is conducted with the hole full of mud fluid, these evils will not occur. The gas will be saved, danger prevented, drilling can be done at night and in cold weather without discomfort, and high-pressure gas will not interfere with nor prevent the working of the tools.

Occasionally strong flows of water interfere with drilling and may prove difficult to shut off. Mud fluid can be used to control the water, and in one instance was successful after several months' efforts to shut off the water with casing and packers.

In fields where wells have to be cased as fast as the hole is made, owing to caving, and where much underreaming is necessary, mud fluid can be used to much advantage. The fluid plasters up the walls of the hole, and the pressure exerted by the column of fluid usually will prevent caving or sand from running into the hole, which would interfere with drilling and underreaming or would " freeze " the pipe. It is possible with this method to carry the casing to much greater depths through a caving or sandy formation. In some Texas and California fields drilling without mud fluid, either with rotary or standard tools, would be practically impossible.

When drilling in mud-laden fluid through a rock, such as limestone, the cuttings from which are hard and coarse, great care should be taken not to drill too much hole at one time. Experience has proved that when too much hole has been made such drillings will settle back around the tools and "stick" them in the well when the bull ropes are thrown on and the temper-screw clamps removed preparatory to drawing out the tools. This sticking of the tools is shown in figure 8. Trouble from this source was experienced in the demonstrations at the Greis well and at the Sinclair, White & Ufer well in the Cushing field.[a]

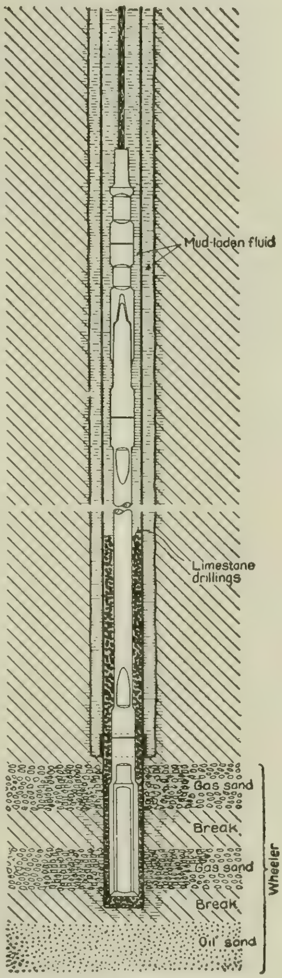

FIGURE 8.—A bit stuck by settling of drillings. Well section is generalized.

From observations of engineers of the bureau, it is recommended that not more than 3 feet of hole should be drilled at any one time in such formation, when fluid is in the hole, unless experience has shown that this figure can be exceeded with safety.

The cuttings should be bailed from the bottom of the hole, and after they have been removed by running the bailer once or twice, it is good practice to bail the fluid from near the bottom of the hole and dump it into the top in order to keep the fluid of the same consistency from top to bottom. The fluid at the bottom of the hole is constantly being thickened from the drillings and by the settling of coarser materials which may not have been removed from the fluid. The fluid is thickened by drilling through clays or shaley formations but is apt to be thinned by drilling through sands.

The mud fluid used in drilling is generally 5 to 15 per cent heavier than clear water. In such a mixture of clay and water, the driller can scarcely distinguish the difference between the action of his tools from that in a hole full of clear water. It must be noted, however, that it can not be expected to drill in the same manner as in a dry hole, and much delay has been caused by failure to recognize this fact. As in a wet hole small tools should be used in order to provide greater clearance, that they may drop more rapidly through the fluid.

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[a] Heggem, A. G., and Pollard, J. A., Drilling wells in Oklahoma by the mud-laden fluid method: Tech. Paper 68, Bureau of Mines, 1914, pp. 15–21.

It frequently happens when drilling through a gas sand, either with rotary tools or with cable tools and a circulator, that the mud fluid is mixed with gas and becomes so light that it will not hold back the gas, and may be blown out of the hole. When gas shows in the fluid in the well, it should be replaced with fresh fluid.

At times gas of such high pressure is struck that the fluid can not be maintained in the hole by its own weight, and it is necessary to stop drilling at intervals and shut in the well under pump pressure until the gas is driven back and the formation sealed off, then drilling may be resumed. Care should be taken, however, not to drill too deep at any one time without applying the necessary pump pressure, and precautions should be taken to put the tools into the well slowly and to withdraw them slowly. Under such conditions it is usually advisable to use the circulator or rotary systems, so that pump pressure can be put on the well at any moment.

It has been the experience in drilling with mud fluid by the use of either rotary or cable tools in California, Texas, and Louisiana, that more than half the instances when wells go " wild " have occurred when the tools were being withdrawn or being run into the hole again.

If there is high-pressure gas in a well being drilled with cable tools, the tools or the bailer should be withdrawn slowly because the rapid withdrawal has much the same effect as swabbing, and may draw in the gas or cause the walls of the hole to cave.

In drilling with rotary tools the drillers may neglect to take account of the displacement of the drill stem when withdrawing it from the hole, so that the level of the fluid may be sufficiently lowered in the hole to cause a blow-out. Trouble has also been caused in cable-tool holes when, to facilitate drilling, the level of the fluid has been lowered too far.

Experience has shown that there is danger in running cable or rotary tools into a hole when the gas pressure nearly equals that of the fluid. When such conditions exist, it is advisable before withdrawing the tools to circulate fresh fluid until all the fluid charged with gas has been removed, and apply pressure with a pump if the gas pressure is high. If these precautions are not taken the well may not blow out when the tools are withdrawn, but may be left in such an unstable condition that it will blow out when the tools are run in again. The agitation of the tools may be sufficient to start the fluid moving, and in a rotary-drilled well the displacement of the drill stem will start the fluid upward and overcome the inertia. The conditions and results are somewhat similar to those in an oil well which may not start flowing until it has been agitated. When such delicately balanced conditions are liable to exist, it is advisable to put pressure on the fluid with a pump; and in a well being drilled with cable tools and the circulator, that fresh fluid be circulated before putting in the tools. In a rotary well fresh fluid can be circulated after every few stands of drill pipe have been put in. In any case, the tools should be run in slowly and carefully. These principles will be varied in detail according to the particular conditions of each case and the equipment being used. Experience in California has shown that these precautions have reduced the risks of a well going wild.

In territory where the depths to the productive strata are not known, oil or gas sands may be drilled through with mud fluid in the hole and their presence not detected if the driller has not carefully examined the drillings bailed from the hole or the returns if a circulator is being used. This has happened many times. Ordinarily it is preferable not to drill a "wildcat" well with fluid in the hole, but provision should always be made for its use to control any flow of gas that may be encountered.

THE USE OF THE CIRCULATOR WITH STANDARD TOOLS.

The method of using a circulator with standard tools is one developed in recent years, principally in the California fields. The system is essentially the employment of the mud-fluid flushing process of the rotary-drilling system in combination with a string of standard tools. The fluid is forced by a pump through the inner casing and returns between the casing and the walls of the hole, bringing the drillings with it. Sand and coarse materials in the fluid are settled out in a series of settling tanks and troughs, and the mud fluid pumped back into the well. Once drilling has started, there is usually enough mud formed in the process so that no more need be mixed, and at times it is necessary to thin the fluid with clear water.

The extra equipment necessary for using the circulator are a slush pump, hydraulic hose, circulator head, and a system of troughs and tanks for the mud fluid. It is also advisable to have two pumps and an extra boiler, and the rig should be provided with a calf wheel. The same principles of construction are used in the circulator head as in the oil saver. The mud fluid is injected through the hydraulic hose which is attached to the circulator head like the flow lines are to the oil saver.

The use of the mud fluid with the circulator in this manner has certain advantages to which the writers wish to call attention, as well as to precautions which must be taken in its use. It has been especially successful in overcoming loose running sands, bowlders, and caving formations. It has also been successfully used where it is desired to underream in a hole troubled by running sands or caving formations. By its use the walls of the hole can be plastered more thoroughly with mud fluid than without circulating, the space between the casing and bore hole kept clear of coarse materials, and the pipe kept freer. If the strata are drilled through with mud fluid circulating in the hole the weight of the fluid will hold up the walls of the hole longer, and generally a much greater depth of open hole can be gained than by the use of clear water. The pipe should not be kept too far above the bottom of the hole, because the cuttings will not flush out and will pack around the tools and interfere with drilling. However, under some circumstances it is necessary to drill farther below the casing than in others, and occasionally so far below that the cuttings will have to be bailed out in the usual manner. By this process casing can be carried farther and with less trouble and expense than by other cable-tool drilling systems under the same difficult conditions, and it will seal off the formations more thoroughly and keep the casing freer.

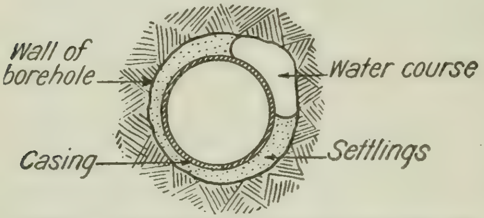

FIGURE 9.—Cross section of well showing how casing may become frozen in drilling by circulator method.

Figure 9 represents a cross section of a well in which mud fluid is being circulated. The cuttings and fluid returning to the surface between the casing and the walls of the bore hole may not be of sufficient volume to fill the space, and consequently the flow will pick out courses on one side of the casing and allow the cuttings to settle and pack on the other side if the pipe is not moved frequently. The passage of the fluid may be free and there may not be any increase in pressure on the circulating pump, but the casing will be found to be tight and in some cases may be impossible to move. Apparently the coarse material settles above the collars and prevents moving the casing upward, but often it will move down of its own weight; or, if not, it can usually be freed by driving a few inches. If the casing can not be freed in this way, the customary methods of moving the casing by jarring, the use of spears, jacks, etc., are employed according to the particular conditions, as though there was no mud fluid in the hole. By moving the pipe as occasion requires, this will be prevented and the fluid will come up uniformly around all sides of the casing and the cuttings will not have a chance to pack. Under some conditions, it is necessary to move the casing as frequently as every 30 minutes. Once circulation has been started it should be kept up continuously until the pipe is landed. Intermittent circulation frequently results in trouble. Those operators who have understood this principle have been uniformly successful, and wherever it is disregarded trouble is almost sure to result.

When a string of casing is seated in mud fluid in a well drilled by the dry-hole system, the use of a circulator will leave the casing freer and in better condition for withdrawing at any future date than by using mud fluid alone. The fluid is circulated until all coarse materials are flushed from the hole and the walls thoroughly plastered. The casing is then seated and the mud plastered onto the walls, and the weight of the column of mud fluid prevents the shales from slaking and coarse materials from falling into the hole and settling around the collars on the casings.

During the past three years the Keck swinging spider and other similar devices have been used with much success in the Coalinga field, California. This apparatus consists essentially of an especially constructed spider with long reins that reach up over the beam, which works between them, so that it is possible to hold the pipe on the casing lines while drilling proceeds, thus enabling the driller to move the casing at any time he may consider it necessary to keep the pipe free without unhitching or even stopping the motion of the tools. This equipment is of considerable value when it is desired to carry an especially long string of casing through any formation where it is difficult to keep the pipe free. It also allows the driller to regulate conveniently the position of the pipe above the bottom of the hole in order to obtain the most favorable results from circulating. In order that there may be room for moving the casing conveniently it is necessary to have a cellar about 25 feet deep, so that a full joint can be handled.

By means of a circulator, casing has been carried to exceptional depths in the fields where there has been much trouble in carrying casing by ordinary cable-tool drilling methods. In one instance 10-inch casing was carried to 3,336 feet by this means in 122 days' time.[a] In this way less casing is needed in deep wells, which reduces the expense and permits the operator to finish his well with a larger sized hole. It has been found from experience that in some fields better time is made with the circulator, the well is finished with fewer accidents and in better shape, and at less expense than under other cable-tool drilling methods. Where the conditions are such that much hole must be drilled with cable tools in mud fluid, such as through caving formations, running sands, artesian water or several high-pressure gas sands, it is believed that it would pay the operator to install a circulator.

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[a] Lombardi, M. E., Improved methods of deep drilling in the Coalinga oil field, California: Bull. Am. Inst. Eng., No. 98, 1915, pp. 209–215.

CASING A WELL WITH THE FLUID IN THE HOLE.

Casing a gas well with the fluid in the hole can be accomplished in a few hours without risk to the workmen. On the other hand, several days are often required to case wells that are blowing, and, on account of the danger, $7 to $10 a day each has to be paid to men to work in the gas.

Carrying the casing while drilling proceeds has been discussed in previous paragraphs. The use of mud fluid is of much benefit where there are caving strata, running sands, or where the hole must be underreamed. Casing has been carried for many hundreds of feet through such formations, where it would hardly be possible to drill a well without using mud fluid. Properly employed, it is a great aid in keeping the casing free.

If it is desired to place mud fluid behind a string of casing, ordinarily it is not advisable to introduce the fluid from the top. If it is poured in from the top, it carries down all caving and coarse material, and this is likely to lodge against the couplings and freeze the casing, or even to form a bridge which will not let the fluid go past. It is better practice to introduce the fluid through the casing and let it come up under the shoe. In this way cavings and coarse lumps are carried up, and if the fluid is circulated long enough they will be flushed out of the hole, leaving it free from material which may settle or lodge against the couplings. When no means of circulating have been provided, the casing should be raised and lowered a distance of not less than the length of one joint several times before seating. Moving the pipe in this manner tends to grind up cavings and lessens the chances of the pipe sticking and should not be delayed, for if it is not done the casing may be stuck within a few hours after the fluid has been introduced.

Should the casing become "loggy" or "stuck" while mud fluid is being used, the best method of loosening the pipe is to put a steady strain on it rather than try to jar it loose. The conditions may be compared with pulling on a long stick sunk deep into heavy mud; a slow, steady pull will have more effect than a quick, hard jerk. If the pipe has been landed, it may be necessary to let the fluid out from behind it by perforating or shooting the bottom joint.

It is advisable to use heavier pipe when using mud fluid than has been customary in the Mid-Continent and Eastern fields; and at any rate, heavy pipe may be used to advantage on the lower end of the string. It is always advisable to screw the casing together securely.

SEATING THE CASING.

When casing is used to exclude water, oil, or gas, or to retain the mud fluid, it must be properly seated in order to make a tight joint.

A common way of seating casing in the Mid-Continent fields is to land the casing with a thread protector screwed onto the bottom. But this practice does not insure good results, even when sand pumpings have been left in the hole before landing the casing to make a tighter seat, and much damage has been caused by such practices where high-pressure gas or water is found. Often the formation in which the casing is landed is not carefully selected and will not provide a secure seat. The writers know of many instances where failure to provide secure seats has let water or gas out by the packers or under the casing, and much damage has resulted. Instances of this kind are cited on page 32. Not knowing the true source of the water has caused unnecessary expense and loss to many operators.

A better practice, which can often be used to advantage, is to provide a long casing shoe 4 or 5 feet in length. After seating the casing, the hole should be drilled a few feet below the seat and tested for absolute tightness, for a small leak is usually enlarged by either water or gas. Drilling should not be continued unless it has been demonstrated that the casing seat is tight.

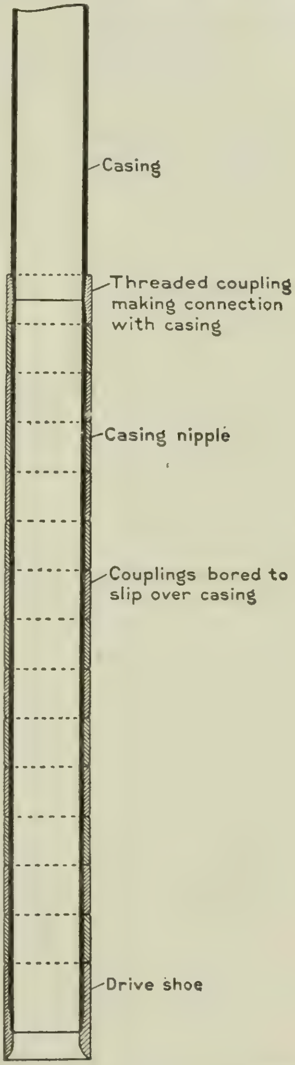
Casing
Threaded coupling making connection with casing
Casing nipple
Couplings bored to slip over casing
Drive shoe

FIGURE 10.—Special long casing shoe.

A special shoe may be made by taking a "pup" joint or short piece of casing, 6 to 10 feet in length, as conditions may require, of the same size as that about to be seated, screwing on one end an ordinary casing shoe and then slipping on reamed-out couplings until they cover the piece of pipe (fig. 10). The top coupling is then screwed down, so that the collars are all clamped between the top coupling and the shoe. By reducing the last 6 or 8 feet of the hole to the size of the outside diameter of the collars, contact is obtained for the entire length of this shoe with the walls of the hole. If a string of casing has been set with a shoe such as above described, the shoe may cause some trouble in pulling the pipe in the ordinary way, when the well is to be abandoned. However, as the bottom joint is reinforced with the collars, the string of casing may be started by using a casing spear, which can be used to better advantage than on pipe without collars, as the slips of the spear will not expand the reinforced casing so much.

In some fields, in order to exclude water from the oil-bearing formations, cementing is resorted to. In many cases cementing and trouble from water entering the oil sands can be avoided by using the long shoe.

The mud fluid is less apt to cut under the casing than clear water, because the fluid does not cut the walls of the hole or penetrate small openings so readily as water, as has been demonstrated wherever mud fluid has been used. Some complaint, however, has been made in the Mid-Continent fields about trouble in holding the fluid behind the casing, even when it has been seated with a long casing shoe or with a packer.

Mud fluid subjects the seat to a greater pressure than has been customary in these fields, because ordinarily when the casing is seated there is not much water behind it, although at a later date water accumulates and the increased pressure may break under the casing, leaving the operator in doubt as to whether the water was coming from the producing sand or from some other source. Many instances of this sort are known. The numerous cases in which gas pressure has unseated several strings of casing in a well indicate that the customary practice in the Mid-Continent field does not provide secure seats and is likely to be the cause of damage later in the life of the well.

Another source of trouble was that after the casing had been seated, the fluid was bailed completely from the well and drilling was resumed without any regard to jarring the casing. If the seat is not in a hard formation, the jar of the tools against the casing may loosen it even when a packer is used, and let the fluid escape from behind the pipe. Great care should be exercised in drilling past the seat, and it is advisable to leave enough fluid in the hole to cover the tools in order to lessen the jar against the casing.

Trouble has often followed the use of the following method of placing mud fluid behind the casing.

The casing is filled with the fluid and then raised, letting the fluid come up around the outside. The instant the casing is lifted off the bottom or off the shoulder on which it has been seated, the rock around the bottom of the casing has to stand the sudden pressure of a column of fluid, which in a hole 1,000 feet deep has a pressure of 500 to 600 pounds per square inch when standing. It is obvious that the sudden rush of fluid is likely to dig out the formations around the bottom of the casing so that it will be difficult to seat it again.

THE USE OF PACKERS.

Packers are used in many wells to shut out water or gas, and a judicious use of packers may occasionally save the use of an extra string of casing. These packers are made in various types to suit special purposes, the usual type consisting of two telescoping steel cylinders inclosed in a rubber cylinder, varied in thickness and length to meet different conditions. The component parts are so arranged that when set the rubber expands outwardly and is intended to fill tightly all irregularities in the wall of the well, thus preventing the passage of water or gas. Packers may be used at the bottom of the casing or at some place above.

Whenever one of these packers is removed after being seated it must be repaired or a new packer substituted before a tight joint can be made again.

It has been found from experience that packers frequently develop defects after they have been set, and not much reliance can be placed on them. They will disintegrate under the action of oil or oil vapors, and in many instances large pieces of rubber have blown out of a gas well when the well was being "blown off," showing that packers can not be expected to last indefinitely no matter how carefully they are set. They can not be set successfully in some formations, and the strata at the points where packers should be placed to protect the well properly may not be suitable for setting packers in. The limitations of packers are especially evident where it is desired to confine gas between two packers or where more than one packer is to be used on the same string of casing. No satisfactory way is known to the writers of adequately testing two packers to determine whether both packers have been set without leaks. For these reasons it is believed to be inadvisable to use packers where their failure would result in material damage or where it is not possible to test them at intervals. Where natural conditions do not provide means of testing a packer, mud fluid can be set behind the casing above it, so that if the packer does fail the fluid will run through and either make the leak known or mud off the sand to be protected so that no damage will result.

One of the advantageous features of using mud-laden fluid is that it provides a test for the conditions behind the casing at all times, and the operator can be quite sure as to whether his well is affording proper protection to the oil or gas.

THE USE OF MUD FLUID IN CEMENTING A WELL.

By any one of a number of processes, cement can be forced up outside of the casing, but it seldom extends more than 100 feet above the bottom. The cement reinforces the casing seat and prevents water or gas from cutting under the casing, or in soft, caving formations prevents the pipe following down the hole as the well is drilled deeper. In so far as cementing relates to this report, the points of interest are the effect that mud fluid in the hole will have on the setting of the cement, and to what extent mud fluid can be used to replace the cementing process or as an additional aid in protecting the well. A further point of interest, and one of probable future value, is whether cement, or similar substances, can be used on the same principle as mud fluid and be forced into porous strata, where it will harden and seal off the strata.

The points to be considered in regard to the effect of mud fluid on the setting of cement are these:

Preliminary to the cement being placed, the mud fluid can be made to exclude all oil, gas, or mineralized water from the hole, and as these substances often interfere with the setting of cement, this is a favorable effect. A further advantage is that the mud fluid will aid in keeping up good circulation behind the casing, which is necessary for successfully forcing the cement up around the outside. On the other hand, if mud fluid becomes mixed with the cement to any appreciable extent, it interferes with the setting. The amount of mixing that will take place will depend largely on the process being used. Many operators of wide experience with the cementing process have advocated that the mud fluid be flushed out first and the hole thoroughly washed with water before the cementing process is started, in order to avoid mixing the mud with the cement and to clean the walls of the hole so that a close bond may be formed between the cement and the formations, because it is not likely that the cement alone would scour off all the mud; and any mud between the cement and the walls of the hole will prevent an actual bond.

Other operators object to washing the hole with clear water because it causes caving and interferes with maintaining the circulation and keeping the pipe free. Many operators do not flush the mud fluid out of the hole and yet have had much success in shutting off water when cementing.

When a string of casing has been landed with mud fluid behind it, all water, oil, or gas is excluded from the hole, and if the fluid remains behind the casing the use of cement is not necessary to protect the well. When, however, the formation in which the casing is landed is such that it will not hold a column of fluid behind the casing, or if there is high-pressure gas below the casing which has not been mudded off and may cut away the casing seat, the cement reinforces the casing seat and will be a great aid. Often the same purpose may be accomplished with a long casing shoe. Even if the cement did not make an actual bond with the wall of the hole it would act as a long casing shoe and reinforce the casing seat; or, even if it did not set in an impervious rocklike mass, it would aid in holding the mud fluid behind the casing. Water might work through the cement or cut a channel between the cement and the walls of the hole, whereas mud fluid will not cut, but will plaster the soft formations and will tend to clog up small openings rather than to pass through them.

When cement only is used, communication between different sands behind the casing will not be prevented, and thus valuable oil and gas deposits may be subject to waste. Neither are the evil effects of unsystematic casing prevented, nor is the casing protected against corrosive waters. In either case much damage may result and make the expense of cementing of no avail, also its presence may make repairing the well very difficult and expensive. If it is possible to cement a well while using mud fluid behind the casing, these evils are prevented, and, furthermore, should any defects develop in the casing or in the seat, the mud fluid will make their presence known and the operator will know the source of his troubles.

The principle of forcing fluid cement or grout into a porous formation to seal it off has been applied with much success in recent years in the Illinois fields, principally by W. W. McDonald, of the Ohio Oil Co., who developed the practical use of the process for shutting out bottom waters in an oil or gas well. The process is described in Bulletin 33 of the State Geological Survey of Illinois.[a] A method of shutting off water behind a casing by cementing under pressure, used by C. A. Hiveley, of the Kern Trading & Oil Co., in the Coalinga field, has also proved successful. Cement has been successfully used in tunnels and shafts to seal off water-bearing sands or creviced rocks. Holes are drilled ahead into the porous rock and fluid cement is forced in under considerable pressure.[b]

By this method it is endeavored to force the cement into the sand and hold it there under pressure, so that it will clog the pores of the sand and harden, thus excluding the water from the hole. The essential difference between using cement or other substances which will set and in using mud fluid is that the mud does not harden sufficiently to prevent its being forced out of the sand by pressure, and it is usually necessary to maintain a column of fluid in the hole to keep the sand sealed. When cement or similar material has once set and excluded the water, it is no longer necessary to maintain a counterbalancing pressure in the hole.

The use of cement in this way opens many interesting possibilities, but how far it may be extended and how to apply it under varying conditions can only be worked out by actual practice.

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[a] Kay, F. H., Petroleum in Illinois in 1914 and 1915: Bull. 33, State Geol. Survey, 1916 (advance extract), p. 22.

[b] Donaldson, Francis, The injection of cement grout into water-bearing fissures: Trans. Am. Inst. Min. Eng., vol. 48, February, 1914, pp. 136–140.

ADVANTAGES OF CASING A WELL IN MUD-LADEN FLUID.

PROTECTING UPPER OIL OR GAS FORMATIONS.

It often becomes necessary to case off oil or gas-bearing sands of lesser commercial value in order to reach more valuable sands below (Pl. II, *A*), and it sometimes happens that water-bearing beds are in close proximity to these sands.

Under the dry-hole method of drilling, extra casing and packers are required to protect fully each one of these formations and as the extra casing delays the work and increases the cost, it is seldom put in. If water occurs below the oil or gas, with no impervious stratum between in which casing can be seated or a packer set, it may be impossible to protect the oil or gas by ordinary methods.

If, however, mud fluid is used, the water will be prevented from injuring the oil or gas. The fluid will drive both the water and the oil or gas back from the hole, and fill the space between the casing and the walls of the hole so that extra casing will be unnecessary. Each porous stratum is sealed off and the contents prevented from entering the hole or moving from one formation into another. (See fig. 11.) In this way, small deposits of oil or gas can be preserved for future use when they may yield greater profits, whereas if they were not protected, they would have yielded the producer little or no returns.

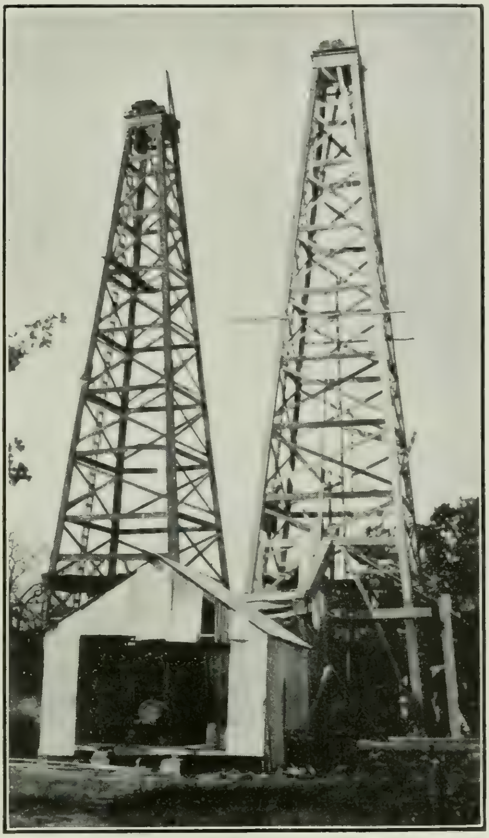
In some fields there are so many different sands or there may be such alternation of water sands with oil and gas sands that it would be impracticable to put in enough strings of casing to protect the valuable deposits unless mud-laden fluid was used. By the judicious use of the mud-laden fluid much casing can be saved and many minor deposits of future value may be protected with slight expense.

MUD FLUID AS A REMEDY FOR UNSYSTEMATIC CASING.

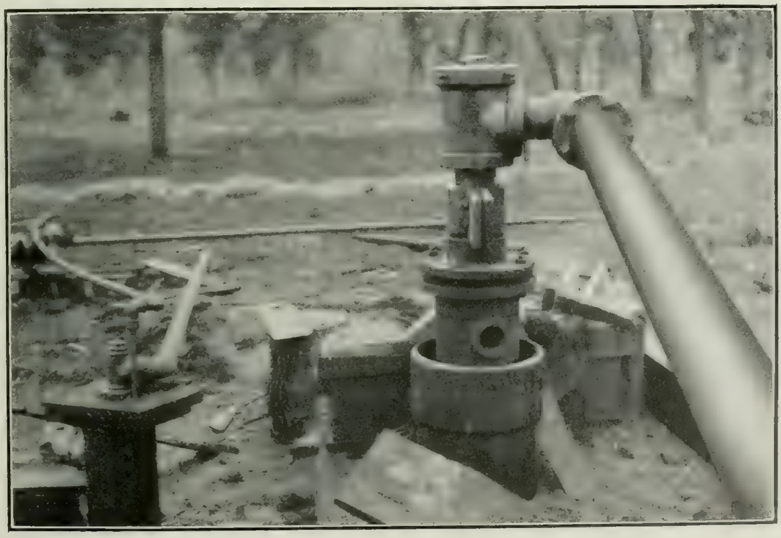
Figures 12 and 13 show the principles of unsystematic casing. If an open space is left behind the casings and they are not landed uniformly according to a system throughout the field in relation to the various sands, a migration of oil, gas, or water will take place that will greatly increase the underground waste of oil and gas, or allow the water to invade oil and gas sands. If there is not some means of getting all the operators in a district to follow the same system in casing wells, great damage may result; as has been proved by experience in the California fields, in the Cushing field, and elsewhere. By placing mud fluid behind the casings such migration and damage can not result.

EFFECT OF MUD FLUID ON KEEPING CASING FREE.

The effect of mud-laden fluid behind the casing, when properly used, is known to be favorable. It has been found from experience



A. TWO ADJOINING WELLS THAT PRODUCE FROM DIFFERENT SANDS.



B. OIL WELL CONNECTED TO FLOW LINE, SHOWING THE TEE CASING HEAD AND FLOW LINE CONNECTED TO SIDE OUTLET.

that it will aid in keeping casing free so that it may be recovered more readily at some later date. The following statement gives the experience of C. P. Clayton, the general superintendent of the Producers Oil Co., in drilling wells in Texas and Louisiana:

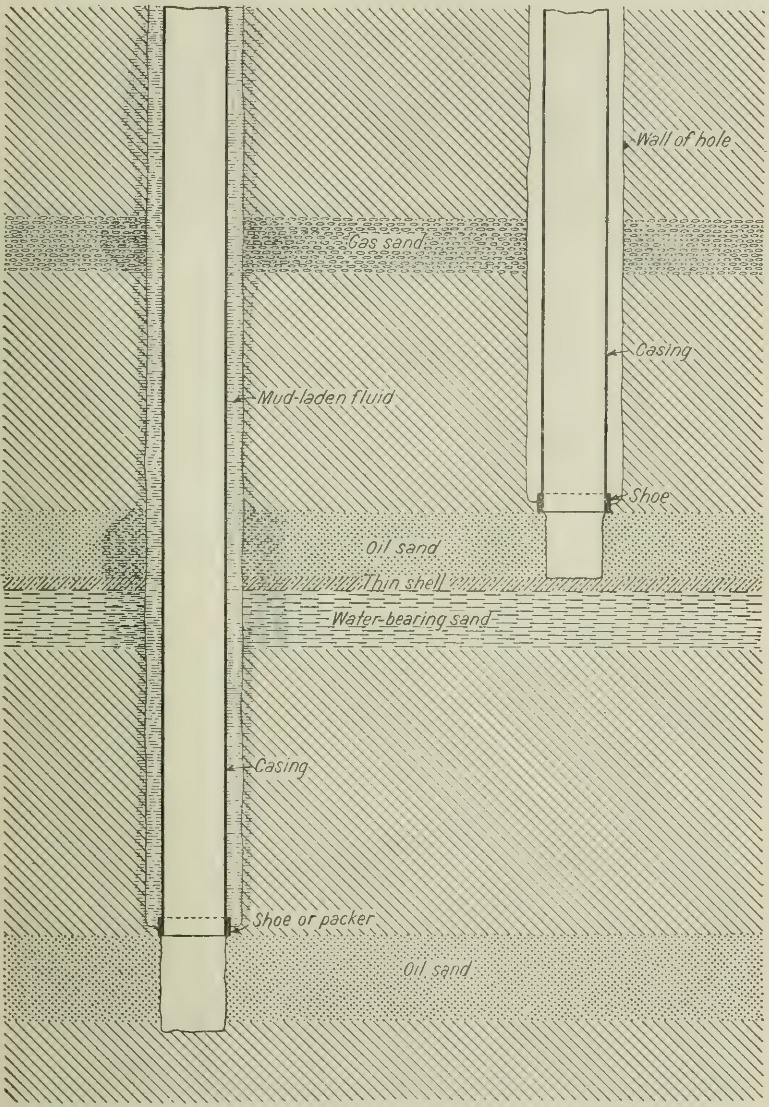


Figure 11.—Sealing upper formations by mud-laden fluid method. Well sections are generalized.

> Setting casing in thick mud has given successful results without exception. My experience has been limited to the Louisiana and Texas fields, but has extended over a number of years and many varying conditions. Our practice

is to carry our drilling mud thick enough to plaster the walls of the hole and drive the mud into any porous rock sufficient to produce a coating on the inside of the hole impervious to circulating water. Then the casing is set in thick mud, and not only the space between the wall and casing filled with mud, but also the space between the outer and inner casing. We are so particular to insure a perfect filling, with heavy mud and not other material, that it is our

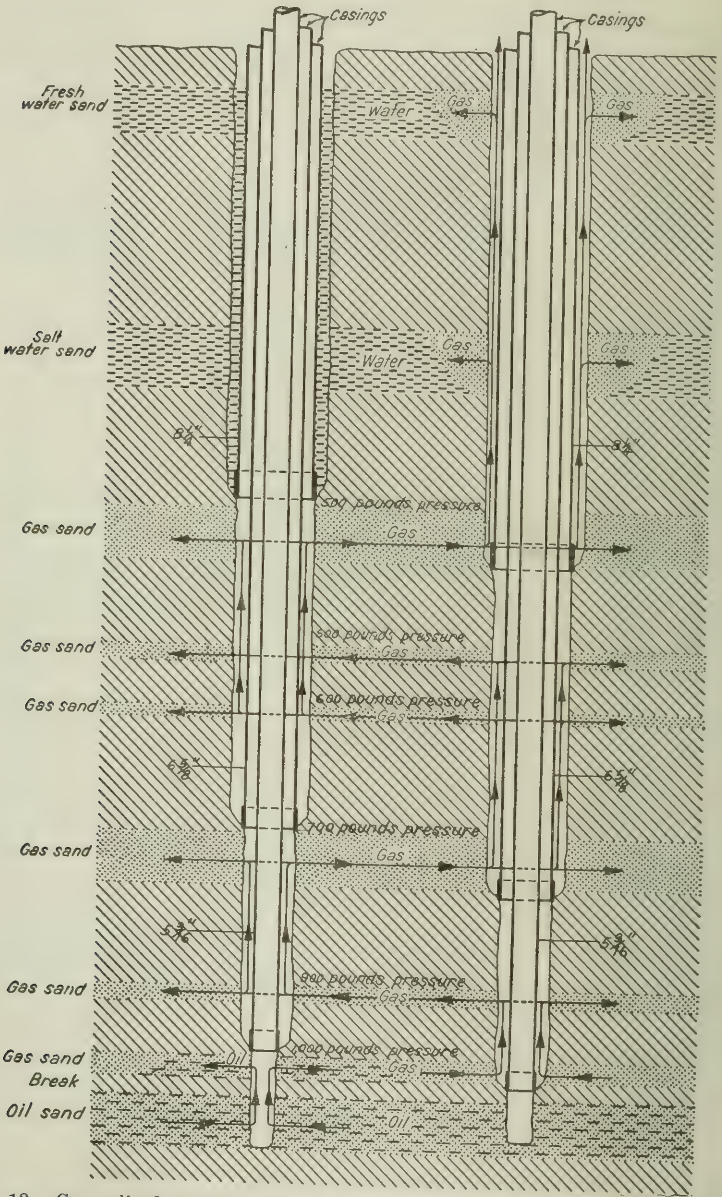


FIGURE 12.—Generalized section showing unsystematic casing of wells. Gas pressure greater than water pressure.

custom to pack the space between the casing at the top with rope to prevent sand or other substances falling in before the space can be filled with mud.

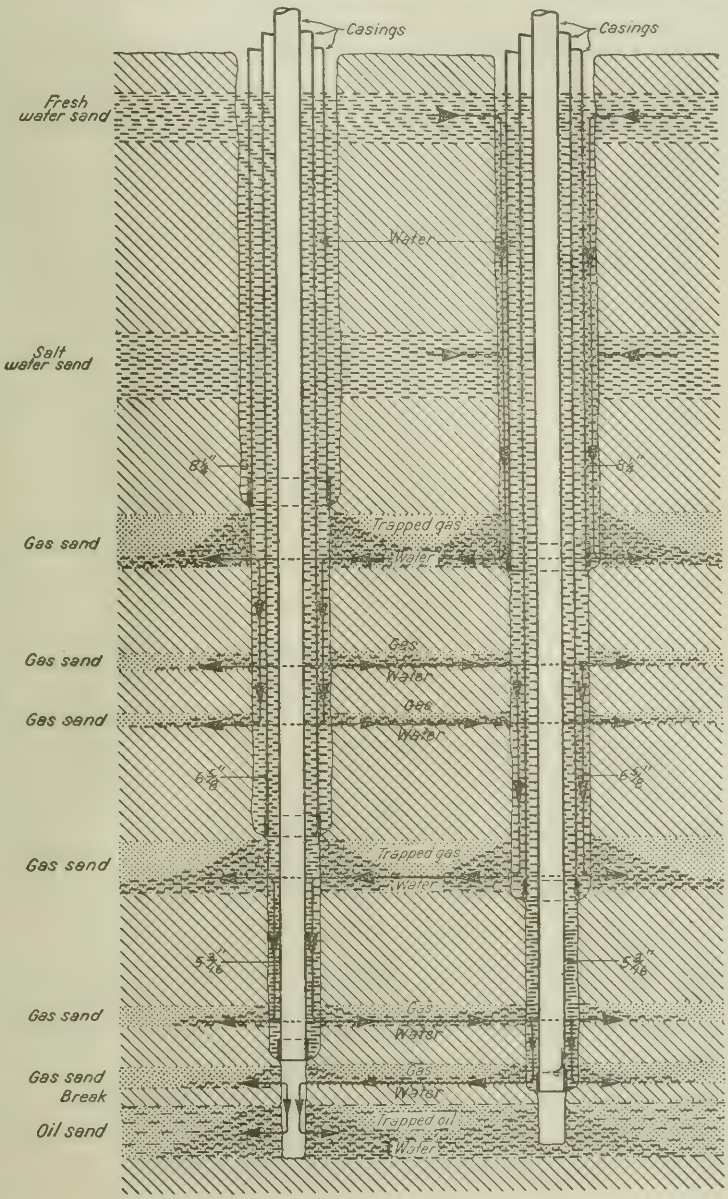


FIGURE 13.—Diagram showing how gas may be wasted by improper casing. The gas is in sufficient volume and under enough pressure to overcome the water; it works up, from the sands of highest pressure, behind the casing and back and forth through the other formations. Much of the gas is lost, and the pressure is greatly reduced. Some of the gas may reach the surface and escape in the air.

You note we make special endeavor to see that the spaces outside of the casing and between the various strings of casing are completely filled with mud.

Mud does not harden sufficiently to prevent pulling the casing. Casing set 5 or 10 years is pulled without difficulty, if properly mudded. Mudding prevents rusting and ordinary disintegration of pipe. Casing set in mud five years was found not to be pitted, whereas casing set in the same field without mud was worthless at the end of five years. Of course, there was some deterioration, but this was offset by the advance in price of casing.

Similar results have been obtained by another large operating company in Texas. In the Lima field, Ohio, drillings from shale were put behind the casing in several hundred wells, but no difficulty was experienced in pulling even second-hand casing. In California casing is so seldom pulled, once it has been set, that there is no definite information on the subject.

Under especially severe conditions of caving or running sands, mud fluid may not permanently hold up the walls and the casing may not be kept free. But even under these adverse conditions the use of mud fluid has been recognized to be more successful than any other method for keeping the pipe free.

MUD-LADEN FLUID PROTECTS CASING FROM CORROSION.

Corrosive waters are a frequent source of trouble and expense in wells. In many fields casing underground is eaten through in two years. The water then becomes a source of much trouble, harming productive strata and eating any other casing or tubing with which it comes in contact. The operator is often misled and may abandon a well, thinking that the water has its source in the productive strata, or he may go to great expense in making ineffective repairs before the true cause is discovered. When a casing has been eaten through, it is often difficult to repair the well, for the casing is likely to be so weakened that it can not be pulled out without being parted; thus the only remedy may be to insert inner strings which in time will also be eaten through, and then the well must be abandoned.

When corrosive waters are present, no ordinary means will fully protect the wells no matter how elaborate and expensive the efforts may be. No combination of casing and packers, nor seating casings with cement, will prevent ultimate damage to the well so long as the destructive water comes into contact with the casing.

Much effort has been made to discover means to protect the casing from corrosive waters. The casing has been coated with tar or other protective substances, but with little favorable effect. Such materials are apt to be worn or scraped off in spots when being placed in the hole. Operators have even gone so far as to use galvanized casing and tubing to prolong its life, or have used casing made by special processes or from alloyed steel. Many claims have been made for the value of the old-style wrought-iron pipe to meet these conditions, but the fact remains that the wrought-iron pipe now obtainable resists corrosive waters no better than steel pipe. The writers know of no material which has proved satisfactory within reasonable costs.

The writers believe that placing mud-laden fluid behind the casing will effectively protect the casing from water, provided the water is not coming from the inside. The column of fluid exerts greater pressure than the water, drives it back from the hole, clogs up the sand, and prevents the water from entering the hole. It follows as a matter of course that the water does not have access to the casing and can not harm it so long as this condition is maintained.

At Lima, Ohio, several hundred wells of one company have been successfully protected by the use of shale drillings. The manager of this company states that formerly casing of either iron or steel would not last longer than two years when placed underground, whereas casing protected in this manner has lasted for over 10 years with no evidence of corrosion.

Two of the largest operating companies in Texas and Louisiana have found that landing their casing in heavy mud fluid prevents rusting and ordinary disintegration of the pipe. As has been previously stated, casing set in mud fluid for five years was found not to be pitted; whereas, casing in the same field seated without mud fluid behind it was worthless at the end of five years.

In California this favorable effect of mud fluid has not been generally appreciated.

FINISHING A WELL.

Closely related to the subject of the proper method of casing and finishing wells, is that of arranging fittings on the head of gas and oil wells.

THE MASTER GATE.

It is a frequent practice in some fields, when a string of casing has been landed, to cut the last or top joint on a level with the derrick floor, and bell out the top with a sledge hammer to present a smooth surface to the drilling line. It is impossible to put screw fittings on the top of a well with the casing thus battered, and usually the well is allowed to go wild if gas is encountered unexpectedly. The short joint of battered casing must be removed while the well is wild, and a new joint, cut and threaded to proper length, must be put on, after which the usual screw fittings for closing in a well may be applied. The same objections apply to drilling nipples. In all wells where there is any reason to believe that high pressures may be encountered, better means of control should be provided. For a comparatively slight extra cost, a master gate or similar device can be placed on the head of the well, as shown in figure 14. This master gate should be packed with asbestos packing throughout, so that if the well catches fire the packing will not be rendered useless. It is also recommended that a pipe T wrench 20 feet long be attached to the wheel of the master gate in a lateral position, so that the valve can be operated from a point 20 feet from the hole. In case of a fire or an accident to the fittings above the master gate, the well can be controlled by closing the valve. These comments apply with equal force to the present method of finishing a high-pressure oil well.

Under the ordinary method of shutting in a high-pressure gas well, arrangements of the fittings is such that should the well catch fire from any small leakage around the casing head, or should one of the valves become foul, the flow of gas could not be controlled. When a well equipped in this way catches fire, as may frequently happen, the head of the well may have to be broken off by a shot before the fire can be extinguished and the well controlled, and the expense and loss to the operator may amount to thousands of dollars. The purpose of the master valve is to serve as a precautionary measure to provide a means for controlling unexpected or strong flows of oil or gas, or to shut off the well in case of danger from fire, or in other emergencies.

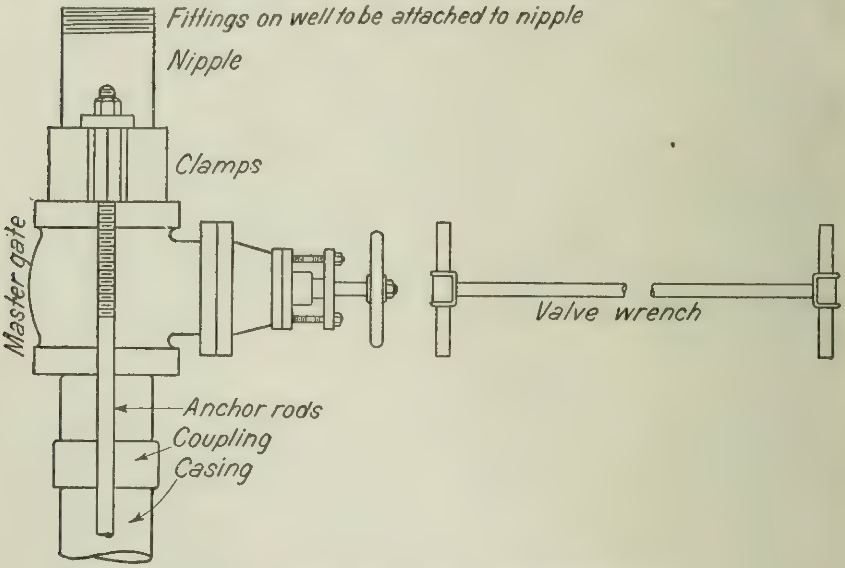


Figure 14.—Master valve fitted on high-pressure well.

It is the custom in the Mid-Continent fields to equip high-pressure oil wells with a casing head, to which are connected flow lines of various sizes. At many wells as many as four 2-inch flow lines are connected to one casing head, the cap being held in place simply by four set screws. This arrangement would be shown in figure 15, were the master valve omitted.

Should the well catch fire, such an arrangement is entirely inadequate. In order to get control of the well, thousands of dollars may have to be spent. If, as is shown in figure 15, a master valve be placed below the fittings in the manner recommended for high-pressure gas wells, the well can readily be controlled, making it an inexpensive job to put out the fire and repair the damage.

DANGER FROM INADEQUATE FITTINGS.

In Plate II, *B*, which shows the usual method of connecting up an oil well, the top opening of the tee is closed by the casing top, which sets completely within the tee and is held in place by four sharp-pointed set screws, arranged radially through the top of the tee. The hole in the casing top, originally provided for the tubing to pass through, is closed by a wooden plug driven in from the under side. The device is useless under high pressure and is dangerous under moderate pressures.

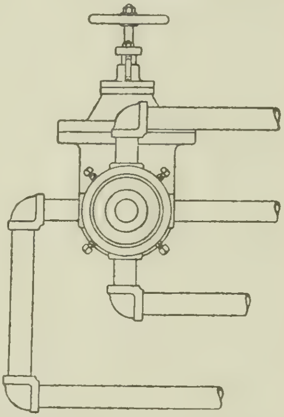


FIGURE 15.—Flow pipes fitted to casing head, with master valve. Top view.

Too much emphasis can not be placed on the necessity for using adequate fittings on high-pressure wells. In spite of the advice of one of the bureau's representatives, fittings designed for a working pressure of only 250 pounds were used on a well having much greater gas pressure, with the result that these fittings were immediately blown up when the well was closed in. Sometimes such fittings have been used for higher pressures without accidents, but it is very risky because, although all fittings are designed with a large margin of safety, they can not be used safely beyond their indicated working pressures, and it is not only dangerous to life and property to employ such fittings, but it is false economy.

On all high-pressure wells especial pains should be taken to anchor the fittings in an adequate manner, and reliance should not be placed entirely on threads, especially in cast-iron fittings.

FINISHING A COMBINATION OIL AND GAS WELL.

In some wells an attempt is made to save the gas by shutting it in between two strings of casing which have a stuffing-box casing head, known as a bradenhead, at the top. Usually there is a considerable distance between the bottom of the one casing and the bottom of the other where the gas is confined in direct contact with the strata penetrated, some of which are usually porous (see fig. 1). Much of the gas enters the more permeable strata, sometimes forcing itself to great distances, and is lost, so that when the well is opened at a later date the gas has escaped to such an extent that the yield is of practically no value to the owner. In some instances it has constituted a formidable danger by forming a stray gas sand, which has resulted in fires at gas wells with attendant loss of life and property. Such a fire was caused in the Cushing field.[a] The oil and gas in a field can not be completely protected so long as they have access to open formations, and this should not be permitted.

Taking gas from between casings through a bradenhead or similar device is not advocated by engineers of the Bureau of Mines, because the gas can not be cared for properly, and it has been found from experience that such a method of producing gas is not satisfactory either in regard to conservation or in the returns to the producer. The pressure and volume are greatly reduced by passing the gas up between the casings, and the flow generally lasts but a short time. If there is open hole either above or below the gas, there is danger of underground waste. If the open hole is above the gas, cavings drop in against the pipe and in time obstruct or entirely prevent the passage of the gas. Even where casings are seated directly above or below the gas, the result is not satisfactory, for there is no way known of ridding the gas of water, and thus the water accumulates and may drown out the gas. It is believed that it will be found a more profitable practice to drill separate wells for the gas. Gas wells drain a far larger area than oil wells, hence it is unnecessary to make each oil well also a producer of gas. A combination well seems justified only as a temporary measure, and after the temporary needs have been served the sands should be mudded off, then much of the casing may be recovered.

In drilling a combination oil and gas well by the mud-laden fluid method, the fluid is put into the well just before the gas sand is reached, after which drilling proceeds to a point just below the gas sand, and the next string of casing is inserted. Before this final string of casing is seated on the bottom, which can be done either with a packer or shoe, as the case may be, the fluid inside the casing is bailed down, that on the outside of the casing being lowered at the same time. A bradenhead is attached to the next outer string of casing and packed. The gland of the bradenhead is prevented from taking a friction hold on the pipe by two or three small blocks of wood. Then, when the fluid has been removed to such depth that its hydrostatic head is less than the gas pressure, the remaining fluid can blow out of the well. The casing is then seated, and the bradenhead bolts, already put in place, are tightened. The seating of the casing in this manner will turn the gas up on the outside of the inner casing and expel through the bradenhead that part of the fluid between the two casings, so that when the well is cleaned, which will not take more than a few minutes, the valves of the bradenhead can be closed and drilling proceed into the oil below in the usual manner. The arrangement of the casing and bradenhead is shown in figure 2. Casings should be landed directly above and below the gas deposit in order to eliminate all danger of underground waste.

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[a] See McMurray, W. F., and Lewis, J. O., Underground wastes in oil and gas fields and methods of prevention: Tech. Paper 130, Bureau of Mines, 1916, p. 14.

A number of methods have been suggested for finishing a well where it is desired to bring gas to the surface between casings without the necessity of landing separate strings of casing directly above and below the gas sand.

Probably some of the suggested combinations of casing and the use of mud fluid, with or without packers, will be successful in recovering the gas without using extra casing and at the same time protecting the gas from other formations. So far as known to the authors, no such methods have been used in actual practice and they are not prepared to say whether the methods will be successful or not.

REOPENING A SEALED STRATUM.

Should it be desired to recover gas from a sand which has been sealed off with mud-laden fluid, the level of the fluid in the hole is lowered until the pressure of the gas is sufficient to force the mud from the sand and to clear the hole. Usually the gas can be recovered in this manner. This has been the experience in the Oklahoma fields, but there are several cases known in California fields, where the sands are looser, that the gas never was recovered in spite of all efforts. If the pressure in a gas sand has been lessened since the mud was forced into it, there may not be sufficient pressure to force out the mud. Washing the hole with clear water may be an aid in recovering the gas, and in a firm sand, such as is found in Oklahoma, shooting may also help.

It should be noted that frequently an oil or gas sand is drowned out by using clear water and the oil or gas can not be recovered, even after the water has been pumped off. It is believed that there is a greater chance of recovering gas that has been sealed off with mud fluid, because the fluid does not penetrate as far into the sand as does water.

It is often possible to unseal oil sands. Many wells are drilled by the rotary or circulator methods through the oil sands with mud fluid in the hole. However, letting mud fluid come in contact with an oil sand from which it is desired to produce should be avoided when possible, because in general it has an unfavorable effect, especially if the sand is of small capacity or of weak pressure.

USE OF MUD FLUID IN ABANDONING WELLS.

Mud-laden fluid can be used to advantage when a well is to be abandoned, and under some conditions is probably the only practical and economical method of fully protecting the oil, gas, or water-bearing formations penetrated by the well. The usual methods prescribed by State laws of using a combination of wooden plugs, cement, and crushed rock are frequently inadequate and will not properly protect the formations, because there may be such a combination of conditions in the hole that these methods will not prevent waste of gas or the flooding of oil or gas deposits with water. Numerous instances are known where wells plugged as provided by the State law have erupted gas and water, and there are undoubtedly many other instances where damage has gone on which was not indicated from surface evidence. The mud-fluid method is simple and will come nearer fitting all cases than any other method known to the authors.

In using this method the hole is cleaned to the bottom and then is filled to the top with very thick fluid. This drives all oil, gas, or water away from the hole and seals off each formation, so that there can be no waste to the surface or intercommunication between different sands. Care must be taken to use very heavy fluid, so that it will not settle much. In addition to filling the hole with fluid, plugs or other materials may be used where it is thought advisable, but it is considered that the best method is to seal off all strata with the mud fluid before anything else is put into the hole.

This method is especially adapted to conditions similar to those described on pages 57 and 58, where the ordinary system of plugging with wooden plugs and rock would have been of no value and neither packers nor cement could be set. It is also advantageous in wells where casing is to be left in the hole or it is desired to leave the well in such a condition that at a later date it may be opened up and brought to production under changed economic conditions. The productive stratum can be protected from direct contact with the fluid by bridging above the stratum or filling the part of the hole through the stratum with sand or similar material, so that the mud is prevented from entering the productive sand. The methods of protecting the sands will have to be varied according to the conditions in each well.

COST OF USING MUD-LADEN FLUID.

Properly applied, the extra cost of using mud-laden fluid will not be great, and, in fact, can be and has been used in such ways as to effect an actual saving in the construction of wells. Wherever the use of mud fluid has been advocated, it has been under such conditions that the first cost will be lessened or the extra cost will be more than compensated by a saving of gas and by the favorable condition in which it will leave the well. The principal ways in which the use of mud-laden fluid may be employed to effect savings are:

1. By preventing surface waste of gas.
2. By preventing underground waste of oil and gas and by protecting minor oil and gas sands.
3. By controlling "wild" wells and preventing fires and other accidents.
4. In drilling through high-pressure sands or through caving formations and running sands.
5. By the use of less casing and fewer packers.
6. By protecting the casing against corrosive waters and ordinary disintegration.
7. By shutting off strong flows of water and protecting fresh water.
8. In repairing and abandoning wells.
9. By leaving the wells in such condition that repairs, damages, and production costs will be less during the life of the property, and the value of the property will be generally increased.

The operator is advised to make provision in advance for preventing trouble and waste rather than to stop them after they have started and have done much damage.

The extra cost of "mudding in" a string of casing is often nominal. Operators in Oklahoma have reported to the engineers of the Bureau of Mines that the actual cost of mudding in a string of casing has been as little as $12, and in a number of instances the average cost was $30. Sometimes the increased wages alone demanded by casing crews for working around gas will be as much as the cost of using mud fluid. The actual cost will, of course, vary with the conditions and the efficiency of those using the method. The figures quoted were for simple conditions, but if foresight is used by the operator, usually the well can be mudded in before difficult conditions develop and while conditions are still simple.

If there is much caving hole, running sands, high-pressure gas, or strong flows of water, drilling with cable tools in mud fluid may be cheaper and even faster than in a dry hole. Under ordinary conditions, however, the actual drilling costs are less in a dry hole, and if there are none of these difficulties, and no oil or gas to be protected, there is no necessity for drilling in mud fluid. Where the gas is found in commercial quantities the saving in gas alone more than compensates for the time lost in drilling in mud fluid, even when there is nothing to interfere with the speed of drilling in a dry hole.

Most drillers have an erroneous impression in regard to the speed of drilling with mud fluid. It is hardly any slower than drilling in clear water, and in caving or running ground it will be much faster. In the cases where it has been efficiently used in the Cushing field it has been found that it is not any slower than the dry-hole method, because no stops were necessary on account of high-pressure gas and other troubles. The prevention of accidents and fires, to say nothing of the lives saved, in high-pressure gas fields are strong arguments for its use.

By using mud fluid one company completed several wells in record times in a part of the Cushing field, where the high gas pressure had caused much trouble in other wells. Drilling was conducted in mud fluid from the time gas was struck until it had been sealed in and cased off. One well was drilled to a depth of approximately 2,700 feet in 33 days. Not only was the gas saved, trouble and expense avoided, but the company was enabled to obtain the advantage of getting its wells into the Bartlesville oil sand before its competitors.

An important saving, and one readily translated into dollars and cents, is in casing. With the mud-laden fluid less casing need be used in drilling a well, and less need be left in after it is finished. That which is left in is protected against corrosive waters and ordinary disintegration. Loss from corrosive waters does not stop with the damage to one string of casing, but will affect other casings, or tubing, and will increase production costs and injure the productive formations. Defects of this sort are certain to lessen profits and affect the value of the property. Mud fluid not only protects the casing, but should defects develop it will usually indicate the source of the trouble or prevent damage.

The extra items of cost consist of the lubricator (or other devices for introducing the fluid), the pump, preparation of the mud fluid, labor, and time.

If the fluid is introduced before the gas is struck, the lubricator is not necessary and the special slush pump can be dispensed with. The lubricator is constructed of standard fittings, so that afterwards the parts can be used around the property or readily disposed of. The slush pump can be used on many wells, and if it is a small one it can be used for other purposes around the lease. Usually a small company can arrange to rent a pump. It is not justifiable to charge the full cost of the lubricator and pump against one well.

If the operator has saved the drillings from shales and clays and kept them free from sand, etc., it will cost him very little to mix his fluid; but if he has not done this, it may be necessary to haul material for making fluid at considerable expense. If the operator has made provision in advance, the items of labor and time will be very small. Ordinarily a few hours is sufficient to control a well after the materials and apparatus have been assembled.

By the application of these principles one company has effected an average saving in first cost of $500 for a large number of wells recently drilled in the Kansas fields, to say nothing of the gas saved and the protection afforded the wells.

Very often the saving in gas is not considered in taking account of the cost of using mud fluid. Numerous instances can be cited from the Oklahoma fields where the gas wasted from wells that could be easily controlled by mud fluid has amounted to many thousands of dollars at current field prices. During a period of 30 days in the spring of 1916 the value of the gas wasted from 12 wells in the Shamrock Pool, Oklahoma, was estimated by representatives of the Bureau of Mines to be $52,800, at the field price of 2½ cents per 1,000 cubic feet.

By using mud fluid such waste of gas can be prevented, minor oil and gas sands can be protected and made sources of future profit, operating costs can be reduced, and the value of the property increased. The conditions which permit waste of gas ultimately lead to encroachment of water and other evils throughout the field, which sooner or later increase costs, lessen profits, and reduce the amount of oil and gas that can be brought to the surface.

Effective conservation in a district means that the market will be more extensive and more stable. Greater expenses will be warranted in gathering and distributing gas. The marketing companies can afford to pay more for the gas, because the cost of equipment will be apportioned to a far larger quantity of gas, and to enter into more favorable contracts and effect economies which only an assured future supply will justify. These facts will more than offset the fear of some operators that the increased quantity of gas will depreciate its value. By adequately protecting the gas, the producer is in better position for making favorable disposal of it, for he will have a greater quantity to sell and will not have to sell it quickly for fear it will waste away. In recent months the field prices in Oklahoma have been considerably increased, in spite of the great quantities of gas developed and the greater proportion now being saved for use. The producers are finding that they are getting into a better position for bargaining.

A few operators have reported wells where the cost of using mud fluid has been very high. It must be noted that the method has been used under the most difficult circumstances, very often after other methods have failed and left the well in damaged condition, or where not using it was entailing an enormous waste of gas. Under the same conditions of high pressure and large volumes of gas, there have been frequent cases where wells have cost an excessive amount employing other methods. The operators have not always given the process a fair trial and, in nearly every case, the excessive expense can be traced back to this fact, or that they have not made adequate preparations nor followed directions. A careful reading of the following demonstrations will show these facts. In some cases a large part of the expenses have been due to unnecessary delay where the operator either did not make provision in advance, when he knew that he was going to strike high-pressure gas which should be saved, or he made no effort to expedite the work. Furthermore, some operators, in their estimates of expense, did not take into account the value of gas which would have wasted, nor did they consider the ultimate saving by the protection afforded the well nor make an effort to take advantage of the methods by which casing can be saved.

THE USE OF MUD-LADEN FLUID IN THE MID-CONTINENT FIELDS.

GENERAL CONDITIONS IN THE MID-CONTINENT FIELDS.

The natural conditions affecting the conservation of oil and gas are unusually complex in the Mid-Continent fields. There are a large number of sands containing gas, oil, or water, so that the drill may penetrate many different sands and in every conceivable combination. Figure 16 (p. 52), Plate III (p. 58), and figure 18 (p. 62) show the combination of sands found in parts of the Oklahoma fields. At Blackwell, Okla., gas sands are found at intervals from within a few hundred feet of the surface to a depth of 3,400 feet. Gas is nearly always found associated with an oil pool and may be in the higher parts of the same sand as the oil or in sands above or below the oil sand. Pressures as great as 1,300 pounds per square inch have been found in some of the deeper wells, and flows of over 50,000,000 cubic feet daily have been reported from a number of wells. The formations resemble those in the fields of States farther east, and the wells are usually drilled under contract by the dry-hole method.

Under such complex conditions drilling in a dry hole is wasteful and dangerous, and to fully protect all the formations by the use of casings, packers, and bradenheads is often either impracticable or impossible. Occasionally the gas will interfere or prevent drilling until the pressure has been reduced. The gas is developed faster than it can be marketed, and to finish the well so as to keep it stored in the ground without waste delays the completion of the well by the dry-hole method and adds to the expense.

In the Cushing field the incentive of obtaining unusually prolific oil wells below the gas sands and minor oil sands led operators to disregard the protection of such sands, with the result that probably not more than 10 per cent of all the gas was utilized, and on many properties it was necessary to purchase fuel within a year from the time they were first developed. Furthermore, the inefficient operating methods led to enormous underground waste and to other conditions which have reduced the recovery of oil and added to the expense. Had the mud-fluid methods been used as demonstrated early in the history of the field by the Bureau of Mines, billions of cubic feet of gas would have been saved at a cost far less than its selling value.

Although it was soon demonstrated that the use of mud fluid would prevent waste, there were no adequate State laws to compel the conservation of the gas. The Department of the Interior had the authority to enforce conservation on the Indian lands, which approximate one-fifth of all the oil lands in Oklahoma, but found it impracticable to prevent waste on most of the Indian lands so long as waste continued in the rest of the field, for the gas moves so freely throughout the sand that it is almost useless to conserve it at any one well, when wells near by do not protect the gas. For the same reasons, those operators who desired to save the gas were powerless so long as their neighbors would not.

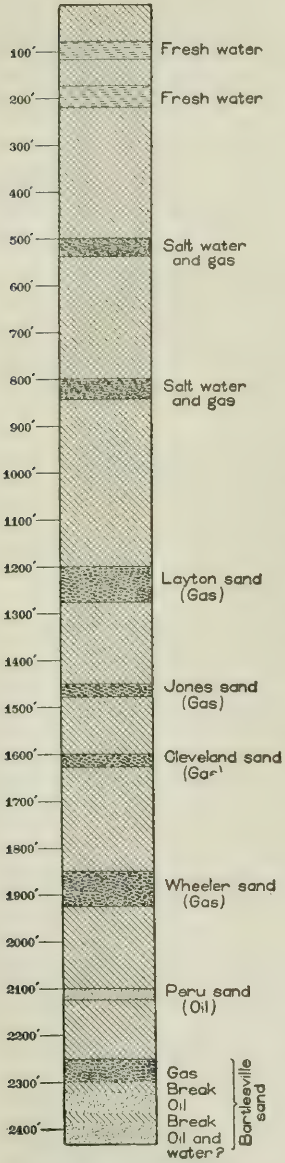

FIGURE 16.—Generalized section showing typical gas and oil sands in north end of Cushing field.

OBJECTIONS TO THE USE OF MUD FLUID IN OKLAHOMA.

Since the mud-fluid method was introduced into the Mid-Continent fields by engineers of the Bureau of Mines in March, 1913, it has been used in over 200 wells whose total open flow was much in excess of a billion cubic feet of gas per day. The cases handled included most of the largest and most difficult wells found during this period. In many instances the method was used after the operators had exhausted all customary means. It has been used to control high pressures, large flows of gas, and wells with defective casing, and to conserve minor sands that could not be protected by other means, because of conditions or the expense of shutting them off.

The method has gone through the period of severe criticism incident to the use of all new or unfamiliar methods. Objections were directed partly against the use of the method itself and partly against the application of conservation to the Oklahoma oil and gas fields. These objections have been largely removed as the operators have become more familiar with the method and its practical utility has been demonstrated. One company alone has "mudded in" over 40 wells in a Kansas field where prevention of waste is not compulsory, and has not only protected the gas but has found that the first cost of the wells has been considerably reduced. In practically every case the troubles reported can be traced back to not using the method efficiently. Prejudice, unfamiliarity, and not making adequate preparations in advance, have been the principal causes of difficulties.

The nature of the objections to the use of the mud-fluid method in Oklahoma may be gained from those brought forth at a hearing before the Corporation Commission of Oklahoma in the latter part of October, 1915. This hearing was called at the request of certain producers in regard to the order promulgated by the commission for the enforcement of the recently enacted gas-conservation law. Some of the largest producing companies in the Oklahoma fields were represented at this hearing, particularly those operating in the Cushing field. It is to be presumed that the objections and arguments presented at this meeting, represented the best opinions of those objecting to the use of the mud-laden fluid at that time. It was the general sense of those present that they were in hearty agreement with the purpose of the law to conserve gas, but that the order of the corporation commission was impracticable, put the producer under an unnecessary expense, and that the facts of underground waste in their opinion did not warrant some of the prescribed measures.

The points brought out by the objectors at this meeting were:

1. Denial of the importance of underground waste and of the necessity for protecting the gas from open hole;
2. That drilling could not be conducted in mud fluid;
3. That drillings could not be bailed from a hole filled with mud fluid;
4. That the mud fluid would settle and dry out behind the casings;
5. That practically all formations in Oklahoma contained sand, and are not suitable for making mud fluid;
6. That mud fluid would cause the tools and the casings to stick.
7. That its use would cause trouble in drilling and additional expense.

A careful reading of this bulletin and the publications referred to in it will supply the answers to these objections.

DEMONSTRATIONS AT WELLS IN OKLAHOMA.

In order to illustrate the use of mud-laden fluid in fields like those of Oklahoma, the following cases are cited. They have been selected to show the diversified conditions under which it can be used. The demonstrations include the control of difficult wells, the saving of gas, the protection of minor oil and gas sands, the repairing of wells, and other uses. Only cases where representatives of the Bureau of Mines were present are included. Some of the demonstrations given in Technical Paper 68, by Heggem and Pollard,[a] have been included here.

CONTROLLING A WELL WHERE USE OF CLEAR WATER FAILED.

Mud-laden fluid must be used with judgment, and clear water must not be used in place of the fluid if good results are to be expected. At a well in the Cushing field, the superintendent decided that clear water would serve as well as the fluid and tried clear water.

The well had been cased to a depth of 1,690 feet with 8-inch casing and was drilled 8 feet into the Wheeler sand May 21, 1913, when the volume of gas liberated became so great that further progress was impossible. The well was allowed to remain open three days when the volume of gas being wasted was found to be 20,140,000 cubic feet a day. The well was then shut in and arrangements were made for continuing the drilling. The gas pressure had fallen considerably, and it was possible to drill 5 feet further, or 13 feet in all, into the Wheeler sand.

On June 2 the owners attempted to exclude the gas from the well by filling it with clear water, using the method described for filling a well with mud-laden fluid. The clear water disappeared into the surrounding beds and caused the walls of the well, where not protected by the casing, to slake and cave into the hole; furthermore, as the water flowed out of the hole as rapidly as it was put in, a column having sufficient head to overcome the gas pressure could not be obtained.

After these efforts proved futile the well was allowed to remain open and waste gas for several days. The owners, being unable to complete the well, appealed to representatives of the Bureau of Mines, and, under their instructions, mud fluid was introduced into the well and the gas "killed" on June 10, after which drilling was resumed.

The well had caved so badly in the meantime that it was difficult to keep the hole clean, and on July 11 a string of 6$\frac{5}{8}$-inch casing was put in, but, owing to the caving, it was two weeks before the casing was seated. The well was shut in as a gas well.

The difficulties encountered were largely the direct result of introducing clear water into the well and starting a cave that was very difficult to overcome.

FILLING WELLS BY THE TUBING METHOD.

A well that presented some unusual difficulties was drilled in August, 1913, near Haskell, Okla., in sec. 18, T. 15 N., R. 15 E.

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[a] Heggem, A. G., and Pollard, J. A., Drilling wells in Oklahoma by the mud-laden fluid method: Tech. Paper 68, Bureau of Mines, 1914, pp. 15–26.

This well had been drilled to a depth of about 950 feet and was cased with 12½-inch casing to a depth of 320 feet. At about 900 feet a gas sand was encountered that yielded a flow of about 40,000,000 cubic feet a day. At 950 feet a bed containing salt sulphur-bearing water was encountered; the water was thrown over the top of the derrick by the gas, and the flow was about 5,000 barrels a day.

An attempt was made to case the well through the gas and water-bearing strata with 10-inch casing, but after the casing had been lowered 520 feet it became "frozen" in a large cave and could not be moved. At this stage the Bureau of Mines was asked to render assistance and a representative of the bureau took charge of the work of getting the well under control.

It was impossible to shut the well entirely in, because the surface casing in the well was too short to withstand the pressure of the gas; consequently it became necessary to resort to the tubing method of inserting the mud-laden fluid, the only water available for mixing the fluid being the salt sulphur-bearing water that was being ejected from the well.

A stuffing-box casing head was placed on the 12½-inch casing and clamped to the 10-inch casing, and a tee casing head was placed on the 10-inch casing. Then 3-inch tubing was lowered through the top opening of the tee to a point a short distance from the bottom of the well and below the gas sand. The space between the tubing and the casing top was packed tightly enough to withstand the pressure of the gas in the well, and a valve was connected to the side opening of the tee.

Mud-laden fluid was pumped into the well through the 3-inch tubing and the gas and salt water displaced by the fluid were allowed to escape through the valve on the side outlet of the tee. By means of this valve the amount of gas and salt water permitted to escape was regulated and the escape of the mud fluid prevented. As the fluid rose within the well it tightly sealed the water and gas strata and finally filled the well.

The time required to bring the well under complete control from the starting of the fluid into the well was 30 minutes. Drilling was resumed, and 8-inch casing was seated at a depth of about 1,000 feet. The mud fluid was then bailed from the inside of the casing and drilling continued to completion without further mishap.

About a year later wells drilled near by found a good supply of gas in the sand sealed off, with no evidence of water.

The tubing method described above was also used in September, 1913, at a well in the Cushing field on sec. 34, T. 18 N., R. 7 E. The condition of this well when the mud-laden fluid method was applied was as follows:

The $6\frac{5}{8}$-inch casing had been frozen at about 1,900 feet and drilling had been continued to the Wheeler formation at about 2,100 feet, where gas was struck that showed a pressure of 600 pounds to the square inch. The volume was not recorded. In trying to loosen the $6\frac{5}{8}$-inch casing with nitroglycerin a premature explosion took place about 820 feet below the surface, shattering the $6\frac{5}{8}$-inch casing and also the 8-inch casing, all other casing having been recovered. When the casings were shattered by this shot, water entered the well from the upper beds and was blown out over the top of the derrick by the gas.

An attempt was made to shut this well in, but as the casing was shattered close to the surface, the gas and water came up outside of the casing, making it impossible to shut off the flow by closing the top; consequently, the tubing method of inserting the mud-laden fluid was used. In 20 minutes from the time that the fluid was started into the well, the well was entirely under control. The fluid not only sealed off the gas, but passed through the hole that has been shot in the casing, penetrated the water bed, and sealed off the water. Drilling was resumed in this well as soon as the tubing through which the fluid had been introduced was removed.

DRILLING A "COMBINATION" WELL.

In September, 1913, the method was successfully used at a well in the Wicey pool near Bixby, Okla. This well had been drilled to a gas sand at about 1,700 feet and $6\frac{5}{8}$-inch casing had been set. The gas had a rock pressure of 810 pounds per square inch and an estimated volume of more than 40,000,000 cubic feet a day. Owing to the great volume and pressure of the gas, the drilling tools could not be lowered into the well, and the Bureau of Mines was asked to render assistance.

On September 5, 1913, under the supervision of a representative of the bureau, a gate valve was placed on the top of the $6\frac{5}{8}$-inch casing, a double joint of 8-inch casing was set up in the derrick on top of the gate valve, and a second gate valve was placed on top of the double joint of casing. Mud fluid was then introduced into the well through the 8-inch chamber.

On September 6 the well was under control and drilling resumed. On September 7 the hole was through the gas sand.

The next day a string of $5\frac{3}{16}$-inch casing fitted with a packer at the lower end was inserted into the well, and on September 9 the fluid was bailed from the well and the gas allowed to clean out the hole. The casing was then seated, thus excluding the gas from the inside of the casing, and drilling was resumed. A stuffing-box casing head or bradenhead was placed on the top of the $6\frac{5}{8}$-inch casing and was packed around the $5\frac{3}{16}$-inch casing to control the gas.

The well was finished by drilling into a lower oil sand and bringing the oil up inside the $5\frac{3}{16}$-inch casing while the gas was recovered between the casings, making a combination well in which the oil and gas were kept separate.

By setting the $6\frac{5}{8}$-inch casing on top of and the $5\frac{3}{16}$-inch casing with a packer immediately below the gas sand, the gas was conducted to the surface without coming in contact with the walls of the hole, so that any possible loss from the escape of gas into other formations was prevented.

Eight-inch casing was used in making the filling chamber, as this was the only size casing available, and the work could be finished in less time than would have been required to obtain two joints of 10-inch casing. In all the work done by the representatives of the Bureau of Mines on various gas and oil wells, standard materials, such as are commonly used about a well, were utilized. The only equipment required which is not commonly used about a drilling well was a pump with which to handle the mud-laden fluid.

PLUGGING AN ABANDONED WELL.

In drilling Nelson No. 1 well, near Vera, Okla., at 1,235 feet a flow of 300,000 cubic feet of gas per day was encountered, which soon exhausted itself. At 1,262 feet the hole was full of water. Drilling was stopped at 1,356 feet on April 19, 1915, and the contractor reported a dry hole and shut down awaiting instructions from the owners. A few hours later the well started to flow gas and water in immense volumes, the flow of gas being variously estimated at 15,000,000 to 40,000,000 cubic feet daily. It was not known from what stratum the gas was coming.

Much time and expense were spent in an effort to separate the gas from the water by using packers so as to make a commercial gas well, but without success. It was then attempted to cement the hole from the bottom up, in order to shut off both water and gas, so that the cement could be drilled out when set, until the gas was encountered, the belief being that the water was bottom water. Cement could not be placed in the well until it was shut in and the water had accumulated and overcome the gas. Then 115 feet of cement was placed in the bottom of the hole and let stand 12 days, after which 20 feet of cement was drilled out, whereupon the water and gas broke in and tangled the drilling line, so that it had to be cut and the tools left in the hole. Many thousands of dollars had been spent in attempting to complete the well, and \$3,500 had been paid the landowner for damage from the salt water. Sand had also been blown out in large quantities and was stated to be 6 inches deep about the well.

On July 1 the aid of the Bureau of Mines was requested. W. F. McMurray, oil and gas inspector, consulted with the officials of the company, and recommended that under the conditions it would be cheapest and most satisfactory to plug this well and to drill new wells for the gas. On account of the condition of the hole, the ordinary systems of using wooden plugs, packers, or cement would not have protected the formation, because it was not known at what place to separate the gas from the water. Furthermore, the walls of the hole had been so damaged that it was hopeless to set in plugs or packers, and the cement would not set on account of the agitation from the gas.

By August 12 the tools had been fished out and the hole cleaned to the bottom. Then 6⅝-inch casing was placed in the hole and connected with a bradenhead to the 8¼-inch casing. Under the direction of Inspector McMurray mud fluid was pumped into the 6⅝-inch casing, letting it come up between the 6⅝-inch and 8¼-inch casings, the displaced gas being controlled by a throttle attached to the bradenhead. Because of the amount of material which had been blown out of the hole and the coarse texture of the gas sand, it took two and one-half days to fill the well with fluid, and it was two and one-half days longer before pressure could be maintained in the well with a pump, showing that the sands were thoroughly clogged. After the sands had been sealed off the well was turned over to the State officials to be plugged according to their regulations.

In this case the method was tried only as a last resort and after a great amount of money and time had been spent in attempting to repair the well. Probably the mud fluid was the only way in which the well could be treated to prevent water entering and damaging the gas sand.

CONTROLLING A HIGH-PRESSURE WELL BLOWING GAS OUTSIDE THE CASING.

In August, 1915, the attention of H. D. Aggers, at that time acting as oil and gas inspector for the Osage Nation, was directed to a gas well owned by White & Sinclair, located on sec. 36, T. 24 N., R. 8 E., which had been blowing gas for a long time. The well was inspected and found to be in a very bad condition, as is shown in figure 17 and Plate III. Gas and water were coming to the surface in large volumes around and between the casings, and had even broken out in large volumes through the surface of the ground for a radius of 300 feet around the well. The well had been completed on May 8, 1914, and shut in, but the casing had not been landed in a secure manner, hence the high-pressure gas soon cut under, until apparently all the sands in the well were connected and the high-pressure gas had access to all the formations from top to bottom. As may be seen

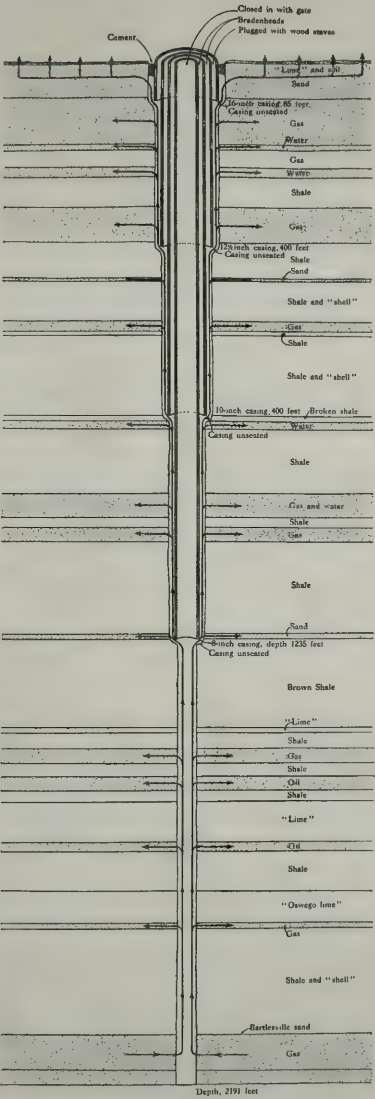

DIAGRAM OF WELL IN OSAGE COUNTY, OKLA.

Shows condition of well and way in which gas escaped to surface. Well was completed May 8, 1914, with an open flow estimated at 22,000,000 cubic feet. When shut in the gas cut under each string of casing, which were landed in shale, and escaped into the other sands. Gas had reached the surface as far as 600 feet from the well, and for a radius of 300 feet was issuing from the ground in large volume, when inspected on August 11, 1915.

from Plate III, there were many different strata which contained gas and some which contained water or oil.

The owners of the well had previously been notified several times to repair the well, but had not known how this might be accomplished. They now agreed to "mud in" the well under the instructions of Aggers.

Mud fluid was first introduced into the space between the 8¼ and 10 inch casings by the lubricator method, under the personal supervision of Aggers. The gas between the 10 and 12½ inch casings and between the 12½ and 16 inch casings was in like manner "killed" by the employees of the White & Sinclair Co. This stopped the escape of gas from outside the casings and also from the vents in the earth around the well. Four-inch tubing with a packer was set on top of the Bartlesville sand and the space between it and the 8¼-inch casing was filled with mud fluid. The 12½-inch casing was then pulled and recovered.

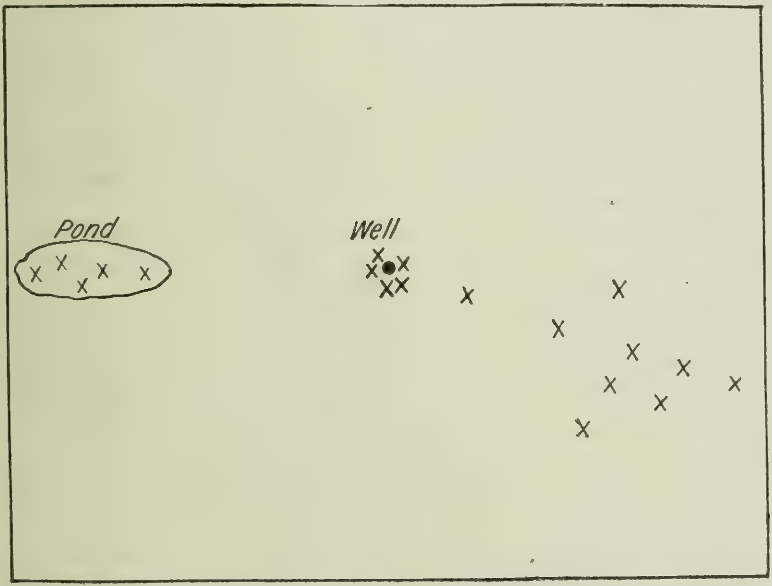

FIGURE 17.—Surface conditions at the well shown in section in Plate III. Gas was escaping with water at places marked with crosses. Where there was no water the gas was not easy to detect. The pond is about 200 feet from the well.

By October 8 the well had been completely shut in and the gas from the Bartlesville sand alone was found to gage 12,500,000 cubic feet daily. On November 6, 1915, the well was inspected by Aggers, who found there was no gas escaping.

The time elapsed between the date the well was brought in and when it was finally placed under control was 518 days. The original flow of gas was reported at 22,000,000 cubic feet daily. The total amount of gas wasted is estimated to be not less than 6,000,000,000 cubic feet. The conditions as found in this field are similar to those in the Cushing field and it is evident that no combination of casing or packers would have protected all the gas sands penetrated by the well.

SHUTTING GAS AND WATER OUT OF AN OIL WELL.

The Foster & Davis No. 2 well was located 2,000 feet distant from the White & Sinclair well, in sec. 36, T. 24 N., R. 8 E., and was the only other well in this pool which had been drilled into the Bartlesville sand. It was originally drilled to 2,225 feet and reached the Mississippi limestone. It was later plugged at 2,159 feet to exclude bottom water. The well was completed January 2, 1915, and showed an initial production of 50 barrels of oil from the Bartlesville sand and a large volume of gas. When inspected in August, 1915, it was producing a small amount of "roily" oil and much water; two or three million cubic feet of gas was escaping through the bradenhead. The company believed that the water was coming from the Mississippi formation, which had been plugged off, and that it would be necessary to abandon the well. Instructions were given to shut in the gas but the company claimed this was an impossibility. On the suggestion of Mr. Aggers, mud fluid was introduced by the lubricator method without difficulty behind the 6⅝-inch casing, which was landed above the Bartlesville sand. The well made 150 barrels of good oil within the next 24 hours and afterwards settled down to a production of 12 barrels of clear oil and 10 barrels of water daily. The use of mud fluid in this case shut off all the gas and most of the water and saved the well to the owners, who otherwise would have abandoned it. It is evident that the 6⅝-inch casing was not seated securely, as thought by the owners, and that most of the water was coming from above the Bartlesville sand and not from the Mississippi limestone below.

In these last two demonstrations the conditions of the wells made it necessary to introduce the mud fluid between the casings from the top, which as a rule is not advisable, because of reasons given elsewhere in this paper.

REPAIRING A SMALL GAS WELL.

A case which would have entailed considerable expense and trouble by other methods was easily remedied by the use of the mud-laden fluid.

On November 8, 1914, the Indian Territory Illuminating Oil Co. completed a small gas well in sec. 22, T. 25 N., R. 11 E., in the Osage

Reservation. About August, 1915, the well commenced to show salt water, which increased in quantity and did much damage to the surface ground about the well. The tubing was pulled and found to be eaten through in several places by the water. In attempting to repair the well a packer and several joints of tubing were inadvertently left in the hole.

The company was preparing to abandon the well, but upon the advice of Inspector H. D. Aggers the following method was used to repair it. Tubing, with a swedge nipple on the bottom and a packer placed above, was put in the hole and the packer set below the 6⅝-inch casing, which was landed above the gas sand. The swedge nipple was set over the tubing which had not been fished out of the hole. This shut off the water. When the well was closed in overnight the water, owing to accumulated pressure, burst past the packer. The 3-inch tubing which had been used was then replaced by 2-inch tubing, as had been advised by Mr. Aggers at first, as in his opinion the volume of the gas was too small to lift the water out of the larger-sized tubing. When the packer was set again, it was placed in the 6⅝-inch casing and all the water was shut off, showing that it was not coming from the gas sand nor from under the casing seat, but had eaten through both the casing and the tubing. Thick mud was then placed behind the casing and between the casing and the tubing. The mud fluid kept the water from entering the well and corroding the tubing. By this method the gas was left dry and in good condition, and the life of a well which would otherwise have been abandoned has been prolonged.

CONTROLLING A HIGH-PRESSURE GAS WELL.

A case similar to the White & Sinclair well No. 2, in the Osage Reservation, was that of the McMan Oil Co.'s well No. 1, on the Mikey farm, located in the southern extension of the Cushing field. The conditions are shown in figure 18.

No attempt was made to shut in the gas until the 8¼-inch casing had been landed below the Layton sand, when the Layton gas was shut in between the 8¼ and 10 inch casings with a bradenhead. The pressure of the gas unseated the 10-inch casing, thus letting the water, which had access to the Bruner sand, also have access to the Layton sand, affecting a total daily flow of 40,000,000 cubic feet of gas. An effort was made to drown out the gas by letting the water stand on the Layton and Bruner sands. A gate was placed on the 10-inch pipe, but when the gate was closed it was torn off almost immediately, along with a 10-inch nipple, and wrecked two sides of the derrick. At the same time the 10-inch casing was unseated. The gas also cut under the packer on the bottom of the

8¼-inch casing. The gas blew the water out of the hole in large volumes, and also reached the surface through many crevices in the ground near the well. Drilling was continued to a depth of 1,975 feet, three more streaks of gas being found, with an additional volume of 5,000,000 cubic feet daily. At this time the company was notified by the corporation commission to repair the well in accordance with the State laws.

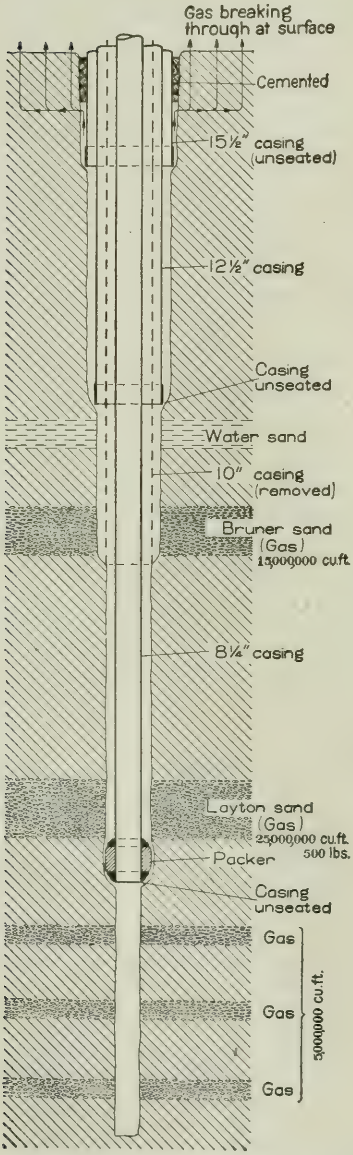

FIGURE 18.—Section showing condition of well No. 1, Mikey farm, south extension of Cushing pool. Formations from driller's record.

On October 1 the field superintendent stated that he had exhausted every effort to repair the well and turned it over to the State conservation officers, James F. York and L. N. McGinley, who requested the assistance of Inspector G. W. McPherson, of the Bureau of Mines. The company was given instructions to provide the equipment and materials necessary for mudding in the well. On October 4 the company furnished a pump, which was, however, of an obsolete pattern, greatly worn, and with valves unsuited for the work at hand. Notwithstanding, an effort was made to mud in the well, in hopes of avoiding further waste. This effort was unsuccessful because the pump could not be run continuously on account of frequent stops for repairs, and furthermore it could not handle a sufficient volume of fluid to overcome the gas. It took the company from October 6 to October 17 to obtain the proper equipment and to haul clay to the well. Lubrication was started at 2 p. m. on October 17, and the well was under control at 5.30 p. m., 500 barrels of fluid being used. Circulation was continued throughout the night and pressure maintained against the Bruner sand by connecting the pump with the bradenhead.

Before this well was killed it was freely predicted by nearly every oil man who had seen the condition of the well that it would be impossible to control, as the mud fluid would be blown out of the crevices as soon as it was put into the well. Lubrication had continued only a short time when the gas and water, which had been erupting in considerable volume at different points around the well, died down and thereafter remained quiet. The reason why the mud fluid did not blow out of the crevices was that the crevices extended down only to a comparatively shallow sand fed by gas derived from the Layton and Bruner sands which came up behind the 8¼-inch casing, the 10-inch, 12½-inch, and 15½-inch casing having been removed, and as soon as the gas in these sands had been sealed in there was no longer communication with the sand from which the crevices were being supplied.

After the well had been mudded in, it subsequently blew out while being drilled to the Wheeler sand at a greater depth, because the drillers bailed down the fluid to facilitate drilling and thus reduced its pressure to less than that exerted by the gas. As soon as the well was "lubricated" again the gas was killed and confined to the sands.

From the time the Bruner sand was struck until the well was mudded in the waste of gas is estimated to have been 15,000,000 to 41,000,000 cubic feet per day. Had the company owning this well provided the necessary equipment in advance, as specified in the order of the corporation commission, this waste need not have occurred and the expense occasioned by shutting in the well would have been avoided. The supposed extra cost of drilling in mud-laden fluid to protect the gas would have been much less than that of bringing the well under control, and the gas saved would have repaid many times the additional expense. The attempted use of bradenheads in this case proved to be utterly impracticable and resulted in conditions that caused great waste, and if they had not been corrected by the application of mud fluid would have done irreparable damage to the field. It was demonstrated later on a property near by that under such conditions wells could be drilled faster and cheaper by using mud fluid than by trying to drill in a dry hole because accidents and delays caused by the gas were avoided.

PROTECTING MINOR OIL AND GAS SANDS.

An illustration of how minor deposits of oil or gas may be protected without extra casing and with little expense is furnished by a well located near Sapulpa, Okla. In this well the Perryman sand at 1,296 feet showed some oil and gas, the Red Fork sand at 1,518 feet showed some oil, the Glenn sand at 1,618 feet showed 4,000,000 cubic feet of gas and 50 barrels of oil at the top and a great quantity of water in the bottom. On account of the water, which could not be separated from the oil sand, the well could not be pumped profitably, and it was therefore deepened to the Lost City sand at 1,903 feet, from which 12 barrels a day was obtained. Then 6⅝-inch casing was landed below the Glenn sand at 1,793 feet. The 8¼-inch casing was pulled, allowing communication between a water sand at 430 feet and the Perryman, Red Fork, and Glenn sands. For three months the gas from the Glenn sand blew gas and water from the outside of the 6⅝-inch casing. The pressure then became so depleted that the water overcame it and drowned out the gas. The well remained in this condition for a year, although the sands affected were of much commercial value in that district.

As the well was on restricted Indian land, the company was notified by Inspector J. C. Fowler that it could not be allowed to remain in such condition. At Fowler's suggestion, the space outside of the 6⅝-inch casing was filled with 75 barrels of mud fluid, at small expense, and to the satisfaction of the owners of the well. It was not even necessary to stop pumping the well while the fluid was being placed behind the casing.

As there was no break between the water and oil in the Glenn sand, it had been found impossible to protect the oil and gas from the water. By using the fluid, no extra casing or packers were necessary, and not only the Glenn sand but also the other two sands were adequately protected. The fluid has been used in other wells where it was desired to drill through an upper productive stratum, in the lower part of which water was found, and possibly its use is the only way in which such deposits can be adequately protected at reasonable expense.

THE USE OF MUD FLUID IN THE ADA FIELD.

The value of having the operations of a field carefully supervised is well illustrated by the work of J. C. Lowrey, in the Ada gas field, Oklahoma. The Ada field is not large, nor does it present unusually difficult problems, but it is of much local importance because it is the only supply of gas in that district and is of great benefit to the town and to the large cement factory located there. Consequently the citizens are desirous of saving the gas and prolonging the supply as far as possible. As usual, the field is divided among many operators and trouble had been experienced in getting them to cooperate. At the request of the Ada Chamber of Commerce, Special Inspector Lowrey was placed in the Ada field in July, 1915, it being arranged that Lowrey's salary and expenses were to be paid by the Ada Chamber of Commerce, and his work was to be under the supervision of the Bureau of Mines. Arrangements were also made for cooperation with the State conservation officers.

After a careful study extending over several weeks, it was found that some of the small number of wells in the field were not in satisfactory condition. Tests were made on these wells, and it was found that water which the operators had thought was coming from the producing sands, was coming under the casing from the upper sands. It was also found that gas sands of minor commercial value were not being protected and that there was danger from unsystematic casing and improperly plugged wells. On Inspector Lowrey's recommendations and through the authority of the State corporation commission and the Department of the Interior these conditions were corrected. Mud fluid was placed behind the casings with much advantage, shutting off all top waters and protecting the minor gas sands.

A peculiar case in the Ada field was reported by Inspector Lowrey. A gas well had just been completed and shut in when it was struck by lightning and the rig burned down, letting the tools which had been hanging in the derrick drop into the space between the casing and the walls of the hole. Gas showing a flow of 3,000,000 cubic feet daily had been "bradenheaded" in between the 6⅝ and 8¼ inch casings. In some manner the tools started a leak in the 8¼-inch casing, so that the water came through and was blown out from between the 8¼ and 6⅝ inch casings. It was not known whether the packer at the bottom had been jarred loose, a leak started around a collar, or a hole cut in the casing. In any event the tools could not be fished out, so that it was unlikely that the casing could be pulled. It was thought that possibly the leak was so small that mud fluid would clog it up and prevent the movement of gas or water through it. Fluid was pumped in between the 6⅝ and 8¼ inch casings from the top and circulated outside the 8¼-inch casing to the surface. Further escape of gas was stopped and water prevented from working into the well, thus leaving the well in good condition.

Another instructive case in the Ada field is that of Allen No. 2 well of the MacThwaite Oil & Gas Co. The well was shut in as a gas well and for a number of days afterwards showed a pressure of 240 pounds, but because there was 34 feet of open hole "bradenheaded" in with the gas sand, Inspector Lowrey advised the company to remedy the condition to avoid possibility of waste. The well was mudded in and the casing reset with a packer at the top of the sand. Within 48 hours the well registered 375 pounds pressure, an increase of 135 pounds over the previous measurement.

REPAIRING A DEFECTIVE GAS WELL NEAR HENRYETTA.

In the course of the inspection of the leases of restricted Indians, Inspector L. W. Courtney found three wells in the Henryetta district which were blowing gas outside of the casing. These wells had been drilled for three years, but had been shut in and not utilized because they were located some distance from any gas lines. The owners of the wells had believed that the gas was from a shallow sand, which at the time the wells were drilled was not considered of commercial value. In consideration of the fact that gas had been escaping steadily from these wells for three years, Courtney thought that the gas should have been exhausted long before if such had been the case. This matter was taken up with the owners of the wells, who decided to place mud fluid outside the casing. This was done, but in a few days the fluid disappeared and the gas came up outside the casing again. On opening the well, fluid was blown out with the gas, as well as pieces of rubber from the packer, showing that the packer leaked. The casing could not be pulled, so fluid was put inside and outside of the casing. When an attempt was made to pull the casing, it parted and was found to be badly corroded. An inner string of casing was landed with a packer and the fluid bailed from the inside, the gas was recovered, and the well was put into good condition.

This case illustrates how frequently the source of trouble from escaping gas or infiltrating water is from leaky packers or casing, whereas the operator may entirely misinterpret the meaning and the source of the trouble. If mud fluid had been placed behind the casings at first, this defect would probably not have developed; or if defects developed in the packer or casing, the column of fluid would either have prevented damage or by leaking away would have made it evident what the defect was, so that the operator would have known how to repair his well and would have been saved much expense and prevented damage to the field.

LAWS AND REGULATIONS RELATING TO OPERATION OF OIL AND GAS LANDS IN OKLAHOMA.

The technological manner of operating oil and gas lands controlled by the Federal Government is under the supervision of the Bureau of Mines. Because of the mobility of oil, gas, and water, these resources in Government lands can not be fully protected unless effective methods are similarly applied to adjoining territory. For these reasons, the Bureau of Mines is directly concerned in the laws of those States in which Government reserves are situated.

From the experience gained by the representatives of the Bureau of Mines in Oklahoma, it is believed that the following State laws, and the Federal regulations governing operations on Indian lands, include the technological features advisable for the proper conservation of oil and gas. Under the regulations for operating Indian lands, the United States Government is interested not only in preventing waste but in protecting the rights of the Indian wards as lessors.

A careful reading of the facts and references given elsewhere in this paper supplies the reasons why these technological features are deemed advisable. Notwithstanding the well-known difficulties involved in regulating oil and gas operations, it is believed that the recent experiences in Oklahoma show that such laws and regulations can be made and enforced and will largely eliminate waste; whereas a review of the history of the oil and gas industry from its inception to the present time shows conclusively that when left to themselves the operators have not conserved and will not conserve the gas nor even fully protect the oil resources.

For the practical conservation of gas, is is necessary to protect the equities of every lessee or owner of gas lands by providing a method for prorating the gas. It has been the constant complaint of oil men and small producers of gas that, not owning pipe lines, they were unable to market the gas except through the large gas-selling companies, and that sometimes these gas-marketing companies would drain a whole field from a few of their own wells which were favorably located and refuse to buy gas from other producers. If conservation were to be applied without providing for equal access to the market, it would be possible for gas companies to reap all the benefits and allow the producers none. It is very much to the interests of the gas companies to protect their investments and the future markets by conserving the gas, and ordinarily they are anxious to treat other producers of gas fairly, because unfair treatment would doubtless make the law impracticable of enforcement or cause its repeal. In Oklahoma all the gas-producing companies have voluntarily agreed to prorate their gas under the supervision of the corporation commission and have waived whatever legal rights they may have claimed.

FEDERAL REGULATIONS RELATING TO RESTRICTED INDIAN LANDS.

The following regulations,[a] aimed to prevent waste of oil and gas on restricted Indian lands in the State of Oklahoma, were promulgated by the Secretary of the Interior on October 20, 1915.

REGULATIONS TO GOVERN OIL AND GAS OPERATIONS ON RESTRICTED INDIAN LANDS IN OKLAHOMA.

DEFINITIONS.

The following expressions, wherever used in the lease and regulations, shall have the meaning now designated, viz:

Superintendent.—The superintendent of any Indian agency in Oklahoma, or any other person who may be in charge of such agency and reservation, and it shall be his duty to enforce compliance with these regulations.

Inspector.—Any person appointed as inspector of oil and gas operations, or who may be designated by the Secretary of the Interior or the Commissioner of Indian Affairs to supervise oil or gas operations on restricted Indian lands, acting under general instructions from the Bureau of Mines and under the supervision of the superintendent.

Oil lessee.—Any person, firm, or corporation to whom an oil-mining lease is made under these regulations.

Gas lessee.—Any person, firm, or corporation to whom a gas lease is made under these regulations.

Leased lands.—The term "leased lands" or "leased premises" or "leased tract" shall mean any restricted lands belonging to Indian allottees within the State of Oklahoma from which restrictions have not been removed, and which have been leased by such allottees with the approval of the Secretary of the Interior.

OPERATIONS.

1. No operations shall be permitted upon any tract of land until a lease covering such tract shall have been approved by the Secretary of the Interior.

Powers and Duties of Inspector.

It shall be the duty of the inspector—

2. To visit from time to time leased lands where oil and gas mining operations are being conducted and to inspect and supervise such operations, with a view

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[a] Regulations to govern oil and gas operations on restricted Indian lands in Oklahoma: Dept. of the Interior, 1915, 8 pp.

to preventing waste of oil and gas, damage to oil, gas, or water bearing formations, or to coal measures or other mineral-bearing deposits, or injury to property or life, in accordance with the provisions of these regulations.

3. To make reports to the superintendent and to the Bureau of Mines as to the general conditions of the leases, property, and the manner in which operations are being conducted and his orders complied with.

4. To consult and advise with the superintendent as to the condition of the leased lands and to submit information and recommendations from time to time for safeguarding and protecting the property of the lessor and securing compliance with the provisions of these regulations.

5. To give such orders or notices as may be necessary to secure compliance with the regulations and to issue all necessary instructions or order to lessees to stop or modify such methods or practices as he may consider contrary to the provisions of such regulations.

6. To modify or prohibit the use or continuance of any operation or method which, in his opinion, is causing or is likely to cause any surface or underground waste of oil or gas or injury to any oil, gas, water, coal, or other mineral formation, or which is dangerous to life or property or in violation of the provisions of these regulations.

7. To prescribe, subject to the approval of the superintendent, the manner and form in which all records or reports called for by these regulations shall be made by the lessee.

8. To prohibit the drilling of any well into any producing sand, when in his opinion and with the approval of the superintendent the marketing facilities are inadequate, or insufficient provision has been made for controlling the flow of oil or gas reasonably to be expected therefrom, until such time as suitable provision can be made.

9. To prescribe or approve the methods of drilling wells through coal measures or other mineral deposits.

10. To determine when and under what conditions a producing well may be drilled deeper and under what conditions a producing well or sand may be abandoned.

11. To require that tests shall be made to detect waste of oil or gas or the presence of water in a well, and to prescribe or approve the methods of conducting such tests.

12. To require that any condition existing subsequent to the completion of a well which is causing, or is likely to cause, damage to an oil, gas, or water-bearing formation, or to coal measures, or other mineral deposits, or which is dangerous to life or property, be corrected as he may prescribe or approve.

13. To approve the type or size of separators used to separate the oil, gas, or water coming from a well.

14. The inspector may limit the percentage of the open flow capacity of any well which may be utilized when in his opinion such action is necessary to properly protect the gas-producing formation.

15. The inspector shall be the sole judge of whether his orders have been fully complied with and carried out.

DUTIES OF LESSEES.

16. Before actual drilling or development operations are commenced on the leased lands, or within not less than 30 days from the date of approval of these regulations in case of producing leases, or leased lands on which such operations have been commenced prior to such approval, the lessee or assignee

shall appoint a local or resident representative within Osage County or Oklahoma on whom the superintendent or other authorized representative of the Department of the Interior may serve notices or otherwise communicate with, in securing compliance with these regulations and shall notify the superintendent of the name and post-office address of the representative so appointed.

In the event of the incapacity or absence from the county of such designated local or resident representative, the lessee shall appoint some person to serve in his stead, and in the absence of such representative, or of notice of the appointment of a substitute, any employee of the lessee upon the leased premises or the contractor or other person in charge of drilling operations thereon shall be considered the representative of the lessee for the purpose of service of orders or notices as herein provided, and service upon any such employee, contractor, or other person shall be deemed service from the lessee.

17. Five days prior to the commencement of drilling operations lessee shall submit, on forms to be furnished by the superintendent, a report in duplicate showing the location of the proposed wells.

18. Lessee shall keep upon the leased premises accurate records of the drilling, redrilling, or deepening of all wells, showing formations drilled through, casing used, together with other information as indicated on prescribed forms to be furnished by the superintendent and shall transmit such and other reports of operations when required by the superintendent.

19. Lessee shall furnish on the 1st day of January and the 1st day of July of each year a plat in manner and form as prescribed by the superintendent, showing all wells, active or abandoned, on the leased lands, and other related information. Blank plats will be furnished upon application.

20. Lessee shall clearly and permanently mark all rigs or wells in a conspicuous place, with the name of the lessee and the number or designation of the well, and shall take all necessary precautions for the preservation of these markings.

21. Lessee shall not drill within 300 feet of boundary line of leased lands except with the consent of the superintendent. Lessee shall not locate any well or tank within 200 feet of any public highway or any building used as a dwelling, granary, barn, or established watering place, except with the written permission of the superintendent.

22. Lessee shall notify the superintendent, in advance, of intention to use the mud-fluid process of drilling, so that the inspector may approve the method and material to be used, in the event the operator is not familiar with this process.

23. Lessee shall provide a properly prepared slush pit into which all sand pumpings and other materials extracted from the well during the process of drilling shall be deposited. Such sand pumpings and materials shall not be allowed to run over the surface of the land. The construction of such pits shall be subject to the approval of the inspector.

24. Lessee shall effectually shut out and exclude all water from any oil or gas bearing stratum and take all proper precaution and measures to prevent the contamination or pollution of any fresh-water supply encountered in any well drilled for oil or gas.

25. Lessee shall protect to the satisfaction of the inspector each productive oil or gas bearing formation drilled through for the purpose of producing oil or gas from a lower formation.

26. Lessee shall place an approved gate valve, or other approved controlling device, on the innermost string of casing seated in the well, and keep same in place and in proper condition for use until the well is completed, whenever

drilling operations are commenced in "wildcat" territory, or in a gas or oil field where high pressures are known to exist, whenever the inspector shall deem same necessary for the proper control of the production from the well.

27. When natural gas is encountered in commercial quantities in any well, lessee shall confine such gas to its natural stratum until such time as the same can be produced and utilized without waste, it being understood that a commercial quantity of gas produced by a well is any unrestricted flow of natural gas in excess of 2,000,000 cubic feet per 24 hours: *Provided*, That if in the opinion of the superintendent gas of a lesser quantity shall be of commercial value the superintendent shall have authority to require the conservation of said gas. Water shall not be introduced into any well where such introduction will operate to kill or restrict the open flow of gas therein.

28. Lessee shall separate the oil from the gas when both are produced in commercial quantities from the same formation or under such conditions as might result in waste of oil or gas in commercial quantities.

29. Lessee shall not use natural gas from a distinct or separate stratum for the purpose of flowing or lifting the oil.

30. Lessee shall prevent oil or gas, or both, from escaping from any well into the open air, and not permit any oil or gas well to go wild or to burn wastefully.

31. Lessee shall not use natural gas in place of steam to operate engines or pumps under direct pressure except with the special permission of the inspector.

32. Lessee shall not use natural gas in flambeau lights, save as authorized or approved by the inspector.

33. Lessee shall use every possible precaution, in accordance with the most approved methods, to stop and prevent waste of natural gas and oil, or both, at the wells and from connecting lines, and to prevent the wasteful utilization of such gas about the well.

34. Lessee shall notify the superintendent a reasonable time in advance of starting work of intention to redrill, deepen, plug, or abandon a well; and whenever the superintendent or inspector has given notice that extra precautions are necessary in the plugging of wells in a particular territory, lessee shall give at least three days' advance notice of such intended plugging.

35. Lessee shall not abandon any well for the purpose of drilling deeper for oil or gas unless the producing stratum is properly protected, and shall not abandon any well producing oil or gas except with the approval of the superintendent or where it can be demonstrated that the further operation of such well is commercially unprofitable.

36. Lessee shall plug and fill all dry or abandoned wells on the leased lands in the manner required, and where any such well penetrates an oil or gas bearing formation it shall be thoroughly cleaned to the bottom of the hole before being plugged or filled, and shall then be filled with mud-laden fluid of a consistency approved by the inspector, from the bottom to the top thereof, before any casing is removed from the well, or in lieu of the use of such mud fluid, each oil and gas bearing formation shall be adequately protected by cement, or approved plugs, or by both such plugs and cement, and the well filled in above and below such cement or plugs with material approved by the inspector.

Where both fresh water and salt water are encountered in any dry or abandoned well which is not being filled with mud-laden fluid as hereinbefore provided, the fresh water shall be sufficiently protected against contamination by cement or approved plugs, or by both such cement and plugs, to be placed at such points in the well as the inspector shall approve for the protection of the fresh water.

37. If such abandoned or dry well be in a coal bed or other mineral vein deposit or be in such condition as to warrant taking extraordinary precautions, the inspector may require such variations in the above-prescribed methods of plugging and filling as may be necessary in his judgment to protect such seam or deposit against infiltration of gas or water and to protect all other strata encountered in the well.

38. The manner in which such mud-laden fluid, cement, or plugs shall be introduced into any well being plugged, and the type of plugs so used, shall be subject to the approval of the inspector.

In the event the lessee or operator shall fail to plug properly any dry or abandoned well in accordance with these regulations, the superintendent may, after five days' notice to the parties in interest, plug such well at the expense of the lessee or his surety.

39. All B-S or water from tanks or wells shall be drained off into proper receptacles located at a safe distance from tanks, wells, or buildings, to the end that same may be disposed of by being burned or transported from the premises.

Where it is impossible to burn the B-S, or where it is necessary to pump salt water in such quantities as would damage the surface of the leased land or adjoining property, or pollute any fresh water, the lessee shall notify the superintendent, who shall give instructions in each instance as to the disposition of such B-S or salt water.

40. Lessee shall make a full and complete report to the superintendent of all accidents or fires occurring on the leased premises.

41. Lessee shall provide approved tankage of suitable shape for accurate measurement, into which all production of crude oil shall be run from the wells, and shall furnish the superintendent copies of accurate tank tables and all run tickets, as and when requested.

42. The superintendent may make arrangements with the purchasers of oil for the payment of the royalty, but such arrangements, if made, shall not relieve the lessee from responsibility for the payment of the royalty should such purchaser fail, neglect, or refuse to pay the royalty when it becomes due: *Provided*, That no oil shall be run to any purchaser or delivered to the pipe line or other carrier for shipment or otherwise conveyed or removed from the leased premises until a division order is executed, filed, and approved by the superintendent, showing that the lessee has a regularly approved lease in effect and the conditions under which the oil may be run. Lessees shall be required to pay for all oil or gas used off the leased premises for operating purposes; affidavits shall be made as to the production used for such purposes and royalty paid in the usual manner. The lessee or his representatives shall be present when oil is taken from the leased premises under any division order, and will be responsible for the correct measurement thereof and shall report all oil so run.

The lessee shall also authorize the pipe-line company or the purchaser of oil to furnish the superintendent with a monthly statement, not later than the 10th day of the following calendar month, of the gross barrels run as common carrier shipment or purchased from his lease or leases.

43. Lessee will not be permitted to use any timber from any Osage lands except under written agreement with the owner, and in all cases where lands are restricted such agreement shall be subject to the approval of the superintendent or inspector. Lessee shall, when requested by the superintendent, furnish a statement under oath as to whether the rig timbers were purchased on the leased tract, and if so, state the name of the person from whom purchased

and give such other information regarding the procurement of timber as the superintendent may desire.

44. Unless expressly provided for in the lease, lessee shall pay to the superintendent for the parties in interest all reasonable damage done to the surface and any growing crops thereon or to improvements on said land in the amount of such damage when agreed upon between the parties in interest. When such amount can not be agreed upon, any of such parties may notify the superintendent, whereupon the superintendent shall notify the parties in interest that if such claims can not be arbitrated satisfactorily, he will, after 10 days from date of notice, investigate the matter of damage, such notice to be sent the lessee, allottee, or his heirs, and such other person as may have informed the superintendent in writing of a claim to an interest in such lands. The superintendent shall thereupon determine the damage and apportionment thereof between the parties in interest, such determination to be final unless an appeal therefrom be taken to the Secretary of the Interior within 10 days from the date of notice of such determination. The decision of the Secretary of the Interior shall be final and conclusive upon all parties concerned. The lessee shall be permitted to proceed with operations pending determination of the amount of damage by the superintendent upon depositing with the superintendent such amount as he may stipulate as sufficient to cover the damages claimed, and such lessee may continue with operations pending appeal upon depositing such additional amount, if any, as may be sufficient to cover the damages as fixed and apportioned by the superintendent, the surplus, if any, to be returned to the lessee. Pending action upon the appeal so much of said amount as is not in dispute by the parties in interest may be disbursed.

45. Failure to comply with any provision of these regulations shall subject the lease to cancellation by the Secretary of the Interior or the lessee to a fine of not more than $500 per day for each and every day the terms of the lease or of the regulations are violated, or the orders of the superintendent pertaining thereto are not complied with, or to both such fine and cancellation, in the discretion of the Secretary of the Interior; *Provided*, That the lessee shall be entitled to notice and hearing with respect to the terms of the lease or of the regulations violated, which hearing shall be held by the superintendent, whose finding shall be conclusive unless an appeal be taken to the Secretary of the Interior within 30 days after notice of the superintendent's decision, and the decision of the Secretary of the Interior upon appeal shall be conclusive.

46. These regulations shall become effective and in full force from and after the date of approval and shall be subject to change or alteration at any time by the Secretary of the Interior.

E. B. MERITT,
Assistant Commissioner of Indian Affairs.
VAN. H. MANNING,
Director Bureau of Mines.
Approved October 20, 1915, DEPARTMENT OF THE INTERIOR.
FRANKLIN K. LANE.

STATE LAWS TO PREVENT WASTE OF NATURAL GAS AND OIL.

NATURAL GAS.

An act[a] approved March 30, 1915, provides for preventing waste of natural gas in the State, for prorating the gas, confers authority on the corporation commission to enforce the act, and prescribes a penalty for its violation. The act reads as follows:

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[a] House bill No. 395, Session Laws of Oklahoma, 1915, ch. 197, pp. 326–329.

An Act To conserve natural gas in the State of Oklahoma, to prevent waste thereof, providing for the equitable taking and purchase of same, conferring authority on the corporation commission, prescribing a penalty for violation of this act, repealing certain acts, and declaring an emergency.

Be it enacted by the people of the State of Oklahoma:

WASTE PROHIBITED.

SECTION 1. That the production of natural gas in the State of Oklahoma in such manner, and under such conditions, as to constitute waste, shall be unlawful.

WASTE DEFINED.

SEC. 2. That the term waste, as used herein, in addition to its ordinary meaning, shall include escape of natural gas in commercial quantities into the open air, the intentional drowning with water of a gas stratum capable of producing gas in commercial quantities, underground waste, the permitting of any natural-gas well to wastefully burn, and the wasteful utilization of such gas.

CONSERVATION OF GAS.

SEC. 3. That whenever natural gas in commercial quantities or a gas-bearing stratum, known to contain natural gas in such quantity, is encountered in any well drilled for oil or gas in this State, such gas shall be confined to its original stratum until such time as the same can be produced and utilized without waste, and all such strata shall be adequately protected from infiltrating waters. Any unrestricted flow of natural gas in excess of two million cubic feet per twenty-four hours shall be considered a commercial quantity thereof; *Provided*, That if in the opinion of the corporation commission gas of a lesser quantity shall be of commercial value, said commission shall have authority to require the conservation of said gas in accordance with the provisions of this act; *And, provided, further*, The gage of the capacity of any gas well shall not be taken until such well has been allowed an open flow for the period of three days.

EXCESS GAS SUPPLY—APPORTIONMENT.

SEC. 4. That whenever the full production from any common source of supply of natural gas in this State is in excess of the market demands, then any person, firm, or corporation, having the right to drill into and produce gas from any such common source of supply, may take therefrom only such proportion of the natural gas that may be marketed without waste, as the natural flow of the well or wells owned or controlled by any such person, firm, or corporation bears to the total natural flow of such common source of supply, having due regard to the acreage drained by each well, so as to prevent any such person, firm, or corporation securing any unfair proportion of the gas therefrom; *Provided*, That the corporation commission may by proper order permit the taking of a greater amount whenever it shall deem such taking reasonable or equitable. The said commission is authorized and directed to prescribe rules and regulations for the determination of the natural flow of any such well or wells and to regulate the taking of natural gas from any or all such common sources of supply within the State, so as to prevent waste, protect the interests of the public, and of all those having a right to produce therefrom, and to prevent unreasonable discrimination in favor of any one such common source of supply as against another.

"COMMON PURCHASER"—FAIR TREATMENT.

SEC. 5. That every person, firm, or corporation, now or hereafter engaged in the business of purchasing and selling natural gas in this State, shall be a common purchaser thereof, and shall purchase all the natural gas which may be offered for sale, and which may reasonably be reached by its trunk line, or gathering lines without discrimination in favor of one producer as against another, or in favor of any one source of supply as against another save as authorized by the corporation commission after due notice and hearing; but if any such person, firm, or corporation shall be unable to purchase all the gas so offered, then it shall purchase natural gas from each producer ratably. It shall be unlawful for any such common purchaser to discriminate between like grades and pressures of natural gas, or in favor of its own production, or of production in which it may be directly or indirectly interested, either in whole or in part, but for the purpose of prorating the natural gas to be marketed, such production shall be treated in like manner as that of any other producer or person, and shall be taken only in the ratable proportion that such production bears to the total production available for marketing. The corporation commission shall have authority to make regulations for the delivery, metering, and equitable purchasing and taking of all such gas and shall have authority to relieve any such common purchaser, after due notice and hearing, from the duty of purchasing gas of an inferior quality or grade.

HEARINGS BEFORE CORPORATION COMMISSION—HOW CONDUCTED.

SEC. 6. That any person, firm, or corporation, or the attorney general, on behalf of the State may institute proceedings before the corporation commission, or apply for a hearing before said commission, upon any question relating to the enforcement of this act; and jurisdiction is hereby conferred upon said commission to hear and determine the same, said commission shall set a time and place when such hearing shall be had and give reasonable notice thereof to all persons or classes interested therein by publication in some newspaper or newspapers having general circulation in the State, and shall in addition thereto cause notice to be served in writing upon any person, firm or corporation, complained against in the manner now provided by law for serving summons in legal actions. In the exercise and enforcement of such jurisdiction said commission is authorized to summon witnesses, make ancillary orders, and use such means and final process including inspection and punishment as for contempt, analogous to proceedings under its control over public service corporations as now provided by law.

APPEALS TO SUPREME COURT.

SEC. 7. That appellate jurisdiction is hereby conferred upon the supreme court of this State to review the orders of said commission made under this act. Such appeal may be taken by any person, firm, or corporation, shown by the record to be interested therein, in the same manner and time as appeals are allowed by law from other order of the corporation commission. Said orders so appealed from, may be superseded by the commission or by the supreme court upon such terms and conditions as may be just and equitable.

POWER OF CORPORATION COMMISSION—RULES AND REGULATIONS.

SEC. 8. That the corporation commission shall have authority to make regulations for the prevention of waste of natural gas, and for the protection of all natural gas, fresh water, and oil-bearing strata encountered in any well drilled for oil or natural gas, and to make such other rules and regulations, and to employ or appoint such agents, with the consent of the governor, as may be necessary to enforce this act.

Acceptance by Pipe Lines.

Sec. 9. Before any person, firm, or corporation shall have, possess, enjoy, or exercise the right of eminent domain, right of way, right to locate, maintain, construct, or operate pipe lines, fixtures, or equipments belonging thereto or used in connection therewith, for the carrying or transportation of natural gas, whether for hire or otherwise, or shall have the right to engage in the business of purchasing, piping, or transporting natural gas, as a public service, or otherwise, such person, firm, or corporation, shall file in the office of the corporation commission a proper and explicit authorized acceptance of the provisions of this act.

Duties of Mine Inspector Unchanged.

Sec. 10. That nothing contained in this act shall be construed to interfere with any duties now imposed by law upon the chief mine inspector of the State or his deputies.

Validity of Several Sections of Act Independent.

Sec. 11. That the invalidity of any section, subdivision, clause, or sentence of this act shall not in any manner affect the validity of the remaining portion thereof.

Penalties for Violation.

Sec. 12. That in addition to any penalty that may be imposed by the corporation commission for contempt, any person, firm, or corporation, or any officer, agent, or employee thereof, directly or indirectly violating the provisions of this act, shall be guilty of a misdemeanor, and upon conviction thereof, in a court of contempt jurisdiction, shall be punished by a fine in any sum not to exceed $5,000 or by imprisonment in the county jail not to exceed thirty days, or by both such fine and imprisonment.

Emergency.

Sec. 13. For the preservation of the public peace, health, and safety, an emergency is hereby declared to exist, by reason whereof this act shall take effect and be in force from and after its passage and approval.

Approved March 30, 1915.

CRUDE OIL OR PETROLEUM.

An act[a] passed by the State legislature on February 11, 1915, to prevent waste of oil, to provide for equitable production, and conferring authority on the corporation commission for its enforcement reads as follows:

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[a] House bill No. 168, Session Laws of Oklahoma, 1915, chap. 25, pp. 28–31.

An Act Defining and prohibiting the waste of crude oil or petroleum, providing for the equitable taking of the same from the ground and conferring authority on the corporation commission, prescribing the penalty for the violation of this act, and declaring an emergency.

Be it enacted by the people of the State of Oklahoma:

WASTE PROHIBITED.

SECTION 1. That the production of crude oil or petroleum in the State of Oklahoma, in such manner and under such conditions as to constitute waste is hereby prohibited.

PRODUCTION AND SALE REGULATED—CORPORATION COMMISSION.

SEC. 2. That the taking of crude oil or petroleum from any oil-bearing sand or sands in the State of Oklahoma at a time when there is not a market demand therefor at the well at a price equivalent to the actual value of such crude oil or petroleum is hereby prohibited, and the actual value of such crude oil or petroleum at any time shall be the average value as near as may be ascertained in the United States at retail of the by-products of such crude oil or petroleum when refined, less the cost and a reasonable profit in the business of transporting, refining, and marketing the same, and the corporation commission of this State is hereby invested with the authority and power to investigate and determine from time to time the actual value of such crude oil or petroleum by the standard herein provided; and when so determined, said commission shall promulgate its findings by its orders duly made and recorded and publish the same in some newspaper of general circulation in the State.

WASTE DEFINED—PROTECTION.

SEC. 3. That the term "waste" as used herein, in addition to its ordinary meaning, shall include economic waste, underground waste, surface waste, and waste incident to the production of crude oil or petroleum in excess of transportation or marketing facilities or reasonable market demands. The corporation commission shall have authority to make rules and regulations for the prevention of such wastes, and for the protection of all fresh-water strata, and oil and gas bearing strata, encountered in any well drilled for oil.

PRODUCTION REGULATED—DISCRIMINATION OF PURCHASER PROHIBITED.

SEC. 4. That whenever the full production from any common source of supply of crude oil or petroleum in this State can only be obtained under conditions constituting waste, as herein defined, then any person, firm, or corporation having the right to drill into and produce oil from any such common source of supply may take therefrom only such proportion of all crude oil and petroleum that may be produced therefrom, without waste, as the production of the well or wells of any such person, firm, or corporation bears to the total production of such common source of supply. The corporation commission is authorized to so regulate the taking of crude oil or petroleum from any or all such common sources of supply, within the State of Oklahoma, as to prevent the inequitable or unfair taking, from a common source of supply, of such crude oil or petroleum, by any person, firm, or corporation, and to prevent unreasonable discrimination in favor of any one such common source of supply as against another.

WELLS GAGED—GOVERNOR TO CONSENT.

SEC. 5. That for the purpose of determining such production, a gage of each well shall be taken under rules and regulations to be prescribed by the corporation commission, and said commission is authorized and directed to make and promulgate, by proper order, such other rules and regulations and to employ or appoint such agents, with the consent of the governor, as may be necessary to enforce this act.

ENFORCEMENT OF ACT—HEARINGS BEFORE CORPORATION COMMISSION.

SEC. 6. That any person, firm, or corporation, or the attorney general on behalf of the State, may institute proceedings before the corporation commission, or apply for a hearing before said commission, upon any question relating to the enforcement of this act, and jurisdiction is hereby conferred upon said commission to hear and determine the same. Said commission shall set a time and place, when and where such hearing shall be had and give reasonable notice thereof to all persons or classes interested therein, by publication in some newspaper or newspapers, having general circulation in the State, and in addition thereto, shall cause reasonable notice in writing to be served personally on any person, firm, or corporation complained against. In the exercise and enforcement of such jurisdiction, said commission is authorized to determine any question or fact, arising hereunder, and to summon witnesses, make ancillary orders, and use mesne and final process, including inspection and punishment as for contempt, analogous to proceedings under its control over public-service corporations, as now provided by law.

APPEALS TO SUPREME COURT—EFFECT ON ORDERS.

SEC. 7. That appellate jurisdiction is hereby conferred upon the supreme court in this State to review the action of said commission in making any order, or orders, under this act. Such appeal may be taken by any person, firm, or corporation, shown by the record to be interested therein, in the same manner and time as appeals are allowed by law from other orders of the corporation commission. Said orders so appealed from shall not be superseded by the mere fact of such appeal being taken, but shall be and remain in full force and effect until legally suspended or set aside by the supreme court.

PENALTY FOR VIOLATION.

SEC. 8. That in addition to any penalty that may be imposed by the corporation commission for contempt, any person, firm, or corporation, or any officer, agent, or employee thereof, directly or indirectly violating the provisions of this act shall be guilty of a misdemeanor, and upon conviction thereof, in a court of competent jurisdiction, shall be punished by a fine in any sum not to exceed $5,000, or by imprisonment in the county jail not to exceed thirty days, or by both fine and imprisonment.

STATE MAY SECURE RECEIVER—EXTENT AND MANNER.

SEC. 9. That in addition to any penalty imposed under the preceding section, any person, firm, or corporation, violating the provisions of this act, shall be subject to have his or its producing property placed in the hands of a receiver by a court of competent jurisdiction, at the suit of the State through the attorney general or any county attorney, but such receivership shall only extend to the operating of producing wells and the marketing of the production thereof, under the provisions of this act.

VALIDITY OF RELATIVE SECTIONS OF ACT.

SEC. 10. That the validity of any section, subdivision, clause, or sentence of this act shall not in any manner affect the validity of the remaining portion thereof.

EMERGENCY.

SEC. 11. For the preservation of the public peace, health, and safety, an emergency is hereby declared to exist by reason whereof this act shall take effect and be in force from and after its passage and approval.

Approved February 11, 1915.

PUBLICATIONS ON PETROLEUM TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines is temporarily available for free distribution. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

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TECHNICAL PAPER 10. Liquefied products from natural gas, their properties and uses, by I. C. Allen and G. A. Burrell. 1912. 23 pp.

TECHNICAL PAPER 32. The cementing process of excluding water from oil wells, as practiced in California, by Ralph Arnold and V. R. Garfias. 1913. 12 pp., 1 fig.

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TECHNICAL PAPER 38. Wastes in the production and utilization of natural gas and means for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

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TECHNICAL PAPER 66. Mud-laden fluid applied to well drilling, by J. A. Pollard and A. G. Heggem. 1914. 21 pp., 12 figs.

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